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2023 Serventy Memorial Lecture
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Introduction

The Serventy Memorial Lecture: supporting students while recognising the important contributions of the Serventy family.

The Serventy Memorial Lecture series began in 1989. This public lecture series aims to raise the profile of Western Australia's extraordinary biodiversity and also collects funds to help support students of natural history in Perth's four public universities: the University of Western Australia, Murdoch University, Curtin University and Edith Cowan University.

During the 20th century, the Serventy family made outstanding contributions to the Western Australian Naturalists' Club, to Australian natural history and to the awareness of environmental issues. There were five members of the Serventy family who contributed: Dr Dominic (Dom) Serventy, Miss Lucy Serventy, Dr Vincent (Vince) Serventy, Mrs Carol Serventy and Mr John Serventy.

Dom Serventy was a founder member of the Club in 1924 when he was just 20 years old. He was the first Secretary / Treasurer, served as President and was editor for 33 years. Dom became an eminent Australian ornithologist, working at CSIRO Wildlife division and publishing a number of landmark books and journal articles during his career.

Lucy Serventy, Dom's sister, contributed a lifetime of voluntary service to the WA Naturalists' Club, was Club Treasurer for over 30 years, and organised junior and senior excursions and many other activities.

Lucy and Dom's brother Vince was a CSIRO researcher and teacher, writer, lecturer and filmmaker, presided over many Club activities and spent his life working in Environmental Education both professionally and in a voluntary capacity throughout Australia. Carol Serventy, Vince's wife, supported his various activities, and John Serventy was Treasurer of the Club in the late 1950s and early 1960s.

The Serventy family's contributions to natural history have been recognised by various organisations. The DL Serventy Medal is awarded each year by BirdLife Australia to recognise Australia's leading ornithologists, in Dom's honour. The Australian Wildlife Society also honour the Serventy family by recognising an environmental volunteer each year with the Serventy Conservation Award.

The WA Naturalists' Club established the Serventy Memorial Fund, now known as the WA Naturalists' Fund, in honour of the Serventy family to encourage young naturalists, help young people take part in excursions and individual projects and, since 2002, has funded natural history prizes for students at WA's four public universities. Winning students receive a $500 prize, as well as a year's membership to the Club, and the opportunity to present a focus talk at a meeting, or write an article for WA Naturalist.

All proceeds from the annual Serventy Memorial Lecture are used to support students of natural history, in recognition of the enormous contributions made by the Serventy family to the WA Naturalists' Club and to conservation and natural history in Australia.

In 2023, the Serventy Memorial Lecture was delivered by Professor Leigh Simmons (Fig. 1) who presented a fascinating and engaging discussion on the topic of Sex, Evolution and the Origins of Biodiversity.

Mandy Bamford

Figure 1. Professor Leigh Simmons, Serventy Lecturer 2023. At Hertz Peak, Tasmania. Photo: F. Simmons.

Sex, evolution, and the origins of biodiversity

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Abstract

Darwin and Wallace recognised that natural selection was responsible for the origin of new species and explained the biodiversity of any given geographic region. Darwin also recognised that it was successful reproduction rather than survival per se that drove diversification, and that sexual selection would be a powerful force of evolution. Here I describe research on the natural history of four western Australian invertebrates, research that has illustrated how sexual selection, through male combat and female choice, can shape the behaviour and morphology of a species and generate the reproductive isolation among populations that results in the origin of new species. Invertebrates are showing global declines in abundance, both in terms of the number of individuals and the number of species. Invertebrate declines are of great concern because these organisms are one of the foundations on which our biodiversity is built. They provide critical ecosystem services, as pollinators, population regulators, recyclers, and nutrient sources for other organisms. As such, invertebrate conservation should be central in our conservation efforts.

Introduction

As naturalists, we are fortunate to live in an extraordinary corner of the world. The southwest of Western Australia (WA) was recognised as a biodiversity hotspot in 2000, in recognition of the more than 7000 vascular plant species, 30 amphibians 280 birds, 60 mammals, more than 175 reptile species and countless insects and other invertebrates that occur here (Myers *et al.* 2000). Many of these species of animals and plants are found nowhere else on earth, they are said to be endemic to the southwest. Our little corner of the world is a veritable paradise for any naturalist.

The definition of a biodiversity "hotspot" is that it contains at least 1500 species of endemic plants and has lost 70% or more of its primary native vegetation due to anthropogenic change (Myers *et al.* 2000). The 2022 State of the Environment report shows that the vast majority of natural habitats in the southwest have been largely removed, replaced or highly modified (Cresswell, Janke & Johnston 2021). The region now has but a tiny fraction of its original

vegetation remaining. We hear much of the extraordinary biodiversity of our flowering plants and the importance of conserving our forests and coastal heaths, or the plight of our native marsupials, and rightly so. However, we hear far less about our invertebrates, and the critical roles they play in our ecosystem. Here, I want to sing the virtues of WA's invertebrates and why they are fascinating and remarkable creatures, and why we should care about their conservation.

I am both a naturalist and evolutionary biologist, interested in the processes responsible for diversification and speciation, and thereby the very origins of biodiversity. It was two great naturalists of the mid to late 1800s, Charles Darwin and Alfred Russell Wallace, who first realised that natural selection was responsible for the evolutionary origin of species (Darwin 1858; Wallace 1858). Both Darwin and Wallace lived in an age of exploration and unprecedented discovery. During their travels around the world, Darwin as naturalist on H.M.S. Beagle and Wallace as a commercial collector across the Malay Archipelago, they realised that the distributions of different species, their similarity and differences, made sense only in the light of adaptation to local conditions. They recognised that the characteristics which allowed an organism to survive in a particular environment would be passed on through subsequent generations. Thus, natural selection acting on organisms from their environments ultimately shaped their form, leading to the origin of new species.

Darwin recognised a second force of selection, sexual selection (Darwin 1871), that was widely rejected as a possible cause of evolutionary change, notably by his co-discoverer of natural selection, Wallace. Darwin argued that any trait that increased its bearers' chances of reproduction when in competition with other individuals of the same sex and species, would be favoured by sexual selection, even if that trait reduced the bearer's ability to survive, because the key to evolutionary change is successful reproduction. Thus, Darwin ascribed the evolution of exaggerated secondary sexual traits, such as the antlers of red deer or the mandibles of stag beetles, the bright plumage of birds of paradise, or the acoustic signals of insects and frogs, to sexual selection. He noted that typically it was males who competed for access to females, either through combat with other males, or through the display of ornaments to females who chose to mate only with those males most finely adorned. Although initially dismissed as a significant factor in the origin of species, the accumulation of research over the last 30–40 years, has revealed how sexual selection can be a powerful agent of evolution, and can drive the speciation process (Zuk & Simmons 2018).

Here I describe some of my own research on four Western Australian invertebrates – ground nesting bees, field crickets, bushcrickets and millipedes – that have contributed to our understanding of how sexual selection can drive the speciation process.

Dawson's burrowing bees, *Amegilla dawsonii*

The immediate image that would come to mind when talking of bees, would be the large hives of honeybees, led by a single queen with many thousands

of workers. Although some Australian native bees are social, mostly those in WA are solitary, with single females constructing their own nest and producing offspring alone. At over 20 mm in length and with a wingspan of 45 mm, Dawson's burrowing bee is our, and indeed one of the world's, largest bees. It is distributed throughout the Gascoyne region of WA where it can be found nesting in claypans, or the anthropogenic equivalent: compacted clay of dirt roads. The males emerge early in the dry season, from mid to late July, and begin to patrol the emergence sites awaiting the females who will start to emerge some 1–2 weeks later. The males, often in their thousands, fly low to the ground, from around 10 am until 4 pm, looking for movement at the opening of existing tunnels or new openings in the ground as female bees dig their way to the surface. When a male detects movement, he will settle next to the emergence hole and with his proboscis taste the emerging individual to determine if it is another male or a female. These bees, like most insects, secrete oils, known as cuticular hydrocarbons, onto their cuticle that serve in waterproofing and communication. Females have a different cocktail of oils to males, and signal their sexual receptivity through these oils to the patrolling males (Simmons *et al.* 2003). A male who has discovered an emerging female soon attracts the attention of rivals who will likewise settle at the tunnel entrance awaiting the female's emergence. When she does leave her tunnel, all males will try to mate with her, frequently resulting in frenzied struggles as each male bites at the other and attempts to control access to the female (Fig. 1a). Eventually one male will succeed in repelling his rivals and the pair scurry to the peripheral vegetation around the emergence site where they will mate (Fig. 1b). Mating is highly skewed toward the very largest males, so that there is strong sexual selection acting on male body size (Alcock 1996b).

An interesting feature of this species is that there are two types of male: large "major" males, i.e. males that are suited for physical combat and mate with the female, and "minor" males that are some 20% smaller in body size than the major males (Alcock 1997). Minor males avoid struggles with major males over mating opportunities, which they have very little chance of winning and can often result in physical damage or even death. Rather, they search the periphery of the emergence sites for females that on occasion escape from these struggles unmated. By using alternative mating tactics, minor males can obtain some reproductive success. We estimated from our observations that 13% of females leave the emergence site unmated and are available to minor males. The evolutionary puzzle is why females make minor sons at all given the low prospects they face in terms of reproduction? Yet, make them they do, and in large numbers, as minor males represent more than 80% of the male population (Alcock 1996a).

Females mate only once (Beveridge *et al.* 2006), after which they change the taste of their cuticular oils to signal their unreceptivity to mating (Simmons *et al.* 2003). During September and early October, females will return to the same area from which they emerged and excavate new tunnels in which to provision offspring. The ground in which they nest is dry baked clay and incredibly hard. Because of this, females must first collect

Figure 1. Dawson's burrowing bee, *Amagilla dawsoni*. (A) Males struggle over access to a newly-emerged females. (B) Only the largest males are successful in mating, and females mate only once in their lives. Photos: L.W. Simmons.

water which they regurgitate onto the dry clay to soften it and allow them to begin excavation. Once they have completed their tunnel, female bees excavate individual brood cells within the tunnel, which they line with wax before conducting a series of provisioning trips to collect pollen and nectar which is stored in the brood cell before finally an egg is laid and the cell sealed (Alcock 1999; Tomkins *et al.* 2001). They collect pollen and nectar from preferred host plants, which largely include species of *Eremophila* and rough bluebells (*Trichodesma zeylanicum*). Dawson's burrowing bees provide important pollination services to these native plants, and in return they obtain pollen and nectar for their own offspring production. It takes a female approximately 20 hours to construct and provision a single brood cell (Alcock 1999), and they provision between 3–11 cells within a tunnel before backfilling it with soil. We found that females become increasingly likely to dig small cells and to produce minor males toward the end of the nesting season, before the tunnels are finally closed. On excavation of a sample of tunnels, we found that females typically place minor male offspring above major males and females, and closest to the tunnel entrance (Beveridge *et al.* 2006). We think that this non-random distribution of offspring types within nests might explain in part the puzzle of why there are so many minor males in the population. A significant source of mortality for these bees occurs as they emerge from their brood cells, digging their way through compacted clay. We might predict that this would be easier for a smaller individual as there is less soil to displace to excavate a narrow tunnel. Minor males do emerge before major males and females, so we think that female Dawson's burrowing bees might make minor males as workers,

with the task of opening up exit tunnels to facilitate the later emergence of their larger brothers and sisters.

Dawson's burrowing bees provide us with a classic example of male contest competition over females, and how it can impose sexual selection on males, in this case for extreme body size. Typically, in the ants, bees and wasps, it is the female that is the larger sex, but in species such as Dawson's burrowing bees where sexual selection acts strongly on male size, we find a reversal in this pattern, with males being the larger sex.

The oceanic field cricket, *Teleogryllus oceanicus*

Darwin's second mechanism of sexual selection, female choice, is based on the notion that female choice imposes selection on the evolution of male traits that signal their worth as potential fathers (Zuk & Simmons 2018). There are a number of potential benefits females can gain from mate choice, including genetic quality of potential mating partners, at one extreme being males of the correct species while at the other, males that provide the genetic constitution necessary for offspring to survive and reproduce. My own work in this area has focussed on a species of field cricket *Teleogryllus oceanicus*, that is native to the northern coastal regions of Australia, from Carnarvon in WA through to Rockhampton in Queensland, and which has spread throughout the islands of the Pacific Ocean, as far as the Hawaiian archipelago, hence its name the "oceanic" field cricket (Fig. 2).

Male crickets have sound producing structures on their highly modified forewings. There is a triangular structure called a "harp", and a circular "mirror" on both left and right forewing. There is also a file on the right wing and a plectrum on the

Figure 2. The oceanic field cricket, *Teleogryllus oceanicus*. Males call to attract females who exert mate choice based on energetically costly calling and courtship songs. Photo: L.W. Simmons.

left, that is dragged across the file as the wings are closed. This action sets up resonance in the sound producing structures which radiate sound. The males produce two types of song, a calling song which functions to attract females from afar, the song you are most likely to hear on warm summer evenings (Simmons *et al.* 2001), and a courtship song that is produced once a female has been attracted (Simmons *et al.* 2010).

Song is energetically costly to produce, requiring an increased energy consumption two to four times that of resting (Mowles 2014). Our work has shown that there is considerable variation among males in the quality of courtship song, and that females show strong preferences for males that produce songs of high quality, those with more sound per unit time that require a greater energy expenditure on the part of the male. We have found that song quality reveals the underlying quality of males; those that are poorly nourished, dehydrated or sick produce poor quality songs (Tregenza *et al.* 2006; Ng *et al.* 2018). Not surprisingly then, females reject males that sing low quality songs, but respond quickly to and are eager to mate with males producing high quality songs. By exercising their mate preferences, females are selecting for males able to better withstand the environmental stresses that affect song quality, and in so doing produce offspring similarly endowed.

The oceanic field cricket provides us with a striking example of rapid and divergent evolution in part of its geographic range on the islands of the Hawaiian archipelago. Sometime in the late 1980s an acoustically-orienting parasitoid fly species was introduced to the islands from its native North America. The fly orients to calling male crickets and scatters live larvae on and around them. The larvae then burrow into the cricket's body and feed on its internal organs before emerging to pupate in the soil, killing the male in the process. I visited Hawaii in 1994 to work with my colleague Marlene Zuk, studying how selection from this fly might impact the songs of the crickets. We found that the same temporal properties of the song that make a male attractive to females also make him attractive to parasitoid flies, imposing natural selection against male song (Zuk *et al.* 1998). Remarkably, sometime in the early 2000s a mutation arose in the crickets on Kauai that affected the venation of the forewings of the male, such that the song generating structures were lost (Zuk *et al.* 2006). Ordinarily such a mutation would be rapidly lost from the population because of female preference for song. However, the presence of the fly on Kauai gave silent males a selective advantage over singers and the mutation has swept rapidly to fixation, so that now almost all crickets sampled from the island of Kauai are silent males.

Remarkably, a second different mutation, involving a completely different set of genes but with a similar effect on the calling structures of male wings, has arisen on the island of Oahu and is currently increasing in frequency as the silent males there similarly have a selective advantage over singing males (Pascoal *et al.* 2014). Yet even more remarkably, in 2017 three new mutations were discovered. On Molokai a mutation has a similar effect to the Kauai and Oahu mutations, but it does not delete the scraper. While the mutation renders a male incapable of normal song, it is

capable of producing a low intensity purring (Tinghitella *et al.* 2018). Two more mutations result in males having either curly wings or short wings (Rayner *et al.* 2019). These genotypes can also produce song, but at an intensity that is too low for the fly to locate. I am excited to see if these new genotypes replace the silent crickets on the islands where they co-occur, given the strong preferences among females for male song. What this fascinating story shows us, however, is that sexual selection and natural selection are powerful forces in nature, driving rapid evolutionary divergence in male sexual traits that can lead to speciation.

The spring bushcricket, *Kawanophila nartee*

Darwin recognised that it was typically the male that was subject to sexual selection via competition for access to choosy females, and so it is males that typically bear the products of selection in the form of secondary sexual traits. But why should sexual selection act so strongly on males? It was this question that first brought me to WA to work on the spring bushcricket, *Kawanaphila nartee* (Fig. 3). The species is distributed from Kalbari in the north through to Kattaning in the south, though my early studies focused on the population in Kings Park. The species feeds exclusively on the pollen and nectar of spring-flowering plants. In Kings Park the eggs hatch after the heavy rains of mid-July, and the juveniles can be found feeding on a succession of spring flowering plants, including grasses and sedges, *Hardenbergia*, *Stirlingia*, *Daviesia*, *Conostylis* and *Burchardia*. Spring bushcrickets reach adulthood in late August to early September, at the peak of the kangaroo paw (*Anigozanthos manglesii*) flowering season, one of their preferred pollen sources, and where they can most easily be found in large numbers competing for access to pollen and nectar. Similar to oceanic field crickets, the males call to attract females for mating. The calling song of this species is inaudible to the human ear, being at a frequency of 50 kHz, so they can only be heard using a bat detector. Once attracted, a female will mount the male and grasp him in a pre-mating amplexus. There is then an assessment period of around 20 min during which it is the male, not the female, who decides whether or not to mate (Simmons & Bailey 1990). If the male chooses to mate, he will reach under the female releasing her grip on him with his mouthparts, before transferring a spermatophore. The pair then separate, and the female will reach back and begin to feed on the large nutritious mass that encases the sperm containing capsule of the spermatophore (Fig. 3b). While she is feeding, over the next hour or so, sperm are transferred to her sperm storage organs (Simmons & Gwynne 1991).

The spermatophore represents a significant investment in mating for males, as its production and transfer to the female constitutes over 20% of his body weight, and it takes him around 3–5 days of pollen feeding before he is able to produce another spermatophore (Simmons 1990). In its turn, consumption of the nuptial gift represents a significant benefit to females, its nutrient content increasing the number of eggs she is able to produce. As such, males and their limited availability of nutritious gifts represent a limited resource for females over which they compete. Sometimes several females will arrive at a calling

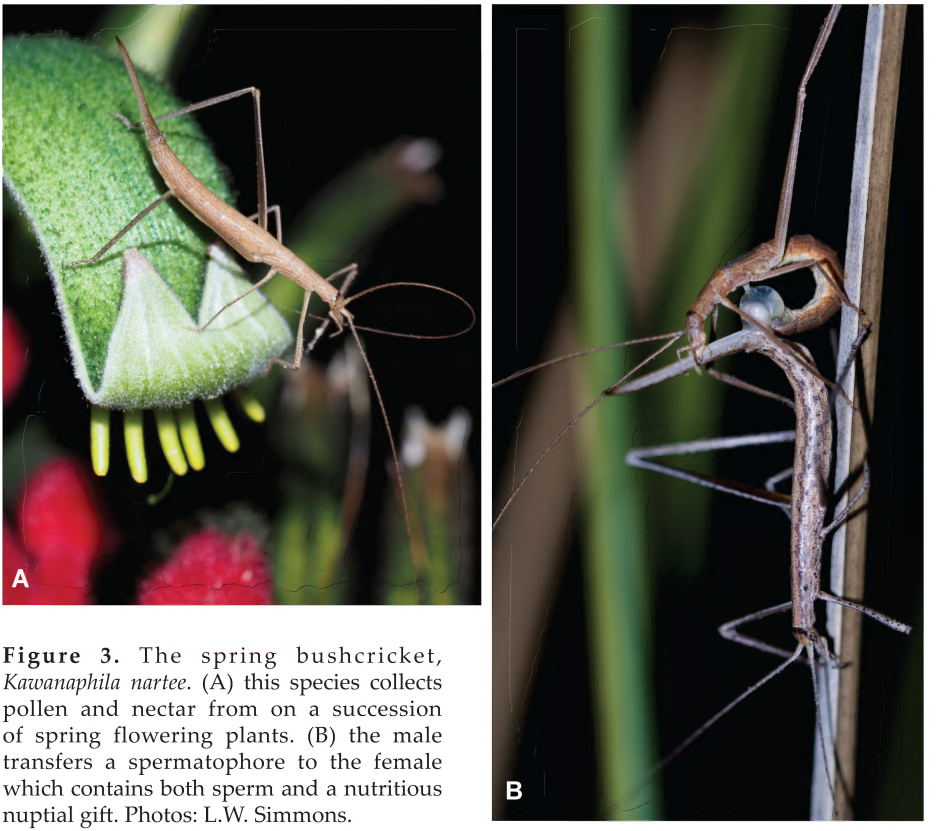

Figure 3. The spring bushcricket, *Kawanaphila nartee*. (A) this species collects pollen and nectar from on a succession of spring flowering plants. (B) the male transfers a spermatophore to the female which contains both sperm and a nutritious nuptial gift. Photos: L.W. Simmons.

male at the same time, upon which they will struggle to displace one another in an effort to amplex the male (Gwynne & Bailey 1999). More often, however, females win the battle for males not through overt aggression but rather via their acute sense of hearing. For unlike males, females have an exaggerated auditory spiracle which affects their ability to detect calling males. Females with larger auditory spiracles are able to locate and arrive at calling males sooner than females with smaller spiracles, and mating is biased toward these females imposing sexual selection on female hearing sensitivity (Hare & Simmons 2021).

The spring bushcricket's behaviour suggests that it is the sex that invests most in reproduction that is a limited resource over which the least investing sex competes; in this case, males invest more in reproduction generating a reversal in the direction of sexual selection which more typically acts on males. Support for this general theory comes from a reversal in the direction of sexual selection that occurs in the middle of the breeding season when grasstrees (*Xanthorrhoea preissii*) begin to flower. Grasstrees offer a super abundance of pollen and nectar, and females can obtain all they need to produce their eggs, no longer

requiring the resources donated by males. In turn, males can regenerate spermatophores rapidly so that they cease to be in limited supply. Once the grasstrees flower it is an abundance of receptive males that compete for access to what becomes a limited supply of choosy females (Gwynne & Simmons 1990; Simmons & Bailey 1990; Simmons 1992).

Our work in Kings Park demonstrated that female hearing sensitivity is under sexual selection, but can it drive an evolutionary divergence in female auditory morphology? To address this question, we sampled bushcrickets from reproductively isolated populations from Cervantes in the north to the Harry Waring Reserve in the south of metropolitan Perth. Using genetic data we obtained an estimate of the magnitude of neutral genetic divergence across these populations, or the expected degree of divergence in the absence of any selection. We then compared the degree of morphological divergence in the size of the auditory spiracles of males and females, finding that female, but not male, spiracle size has diverged far more than would be expected under a model of neutral divergence (Hare *et al.* 2022). Moreover, females from the Koondoola Regional Bushland have the largest auditory spiracles of all populations, and are associated with a habitat that is relatively depauperate of the species preferred food sources, and where sexual selection on females is expected to remain throughout the breeding season.

The marri millipede, *Antichiropus variabilis*

The spring bushcricket shows us that females, like males, can be subject to sexual selection, and that in general it is the sex that invests least in reproduction that will compete for mating opportunities and bear the products of sexual selection. It also shows us that those products may not always be the exaggerated weapons or ornaments that we typically envisage as distinguishing males from females. Rather, other functional traits that contribute to mate acquisition can also be subject to sexual selection. The marri millipede offers an example of how sexual selection can drive the evolution of animal genitalia.

The marri millipede is a widespread species, ranging from Gingin in the north down to Shannon in the south. As its name suggests, it occurs in the mixed woodlands of jarrah and marri where it feeds on decaying marri leaf litter. It is active in the wet months of May to September, and can be found in open areas of woodland, and is particularly easy to find marching across the edges of granite outcrops, or the cycle paths in Kings Park, following heavy rains. At first glance the marri millipede does not seem to be a species subject to sexual selection; there is no sexual dimorphism in body size or colour, and they do not appear to have any behavioural strategies for mate attraction or competition, finding each other opportunistically as they move through the leaf litter. But the males do have remarkably complex and highly modified legs on the 7th abdominal segment, which act as secondary genitalia used in the transfer of sperm to the female during copulation (Wojcieszek *et al.* 2012).

The male collects sperm from his gonopores, essentially charging the gonopods which are then inserted into the gonopores of the female.

The gonopods reach deep inside the female's body and enter paired structures called receptacula where sperm are stored prior to their use in the fertilization of eggs (Fig. 4). Copulation typically takes around 20 min, after which the pair split up and go their own ways, the male in search of additional females with which to mate. Using genetic markers to assign parentage, we were able to show that the female mates with multiple males, but that the last male to mate will fertilize 70% or more of the eggs she ultimately lays (Wojcieszek & Simmons 2011). During copulation, the male must displace or remove sperm from a female's previous mates in order to achieve this greater than random share of parentage, and the shape of a male's gonopod has a significant effect on his paternity share. Gonopod shape is thereby subject to sexual selection through the competition for fertilizations.

We asked whether this sperm competition could drive the evolution of genital shape across populations of marri millipedes. We collected males and females from seven genetically isolated populations and used DNA sequence data to estimate the levels of neutral genetic variation among these

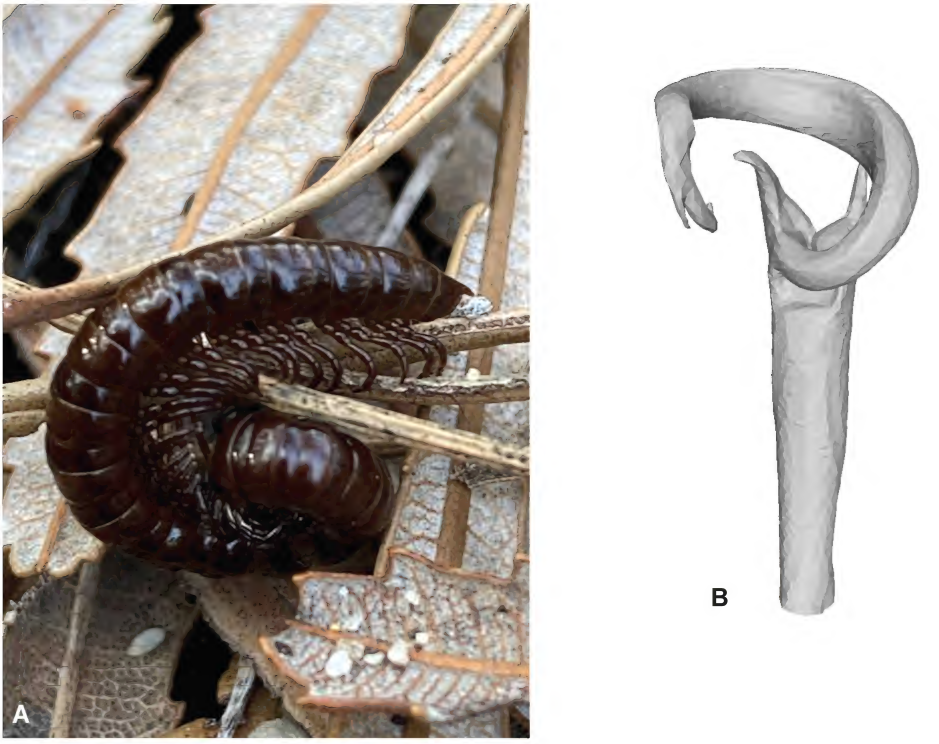

Figure 4. The marri millipede, *Antichiropus variabilis*. (A) Adult male. (B) MicroCT scan of the secondary genitalia (gonopods) of the male. The shape of the gonopods diverges rapidly among populations and species due to sexual selection. Photo: L.W. Simmons.

populations, as we did with the spring bushcrickets. We then used microCT scanning technology to quantify variation in the shape of the male gonopod and the shape of the female receptaculum. Most of the variation in males occurs in the solenomere that enters the receptaculum, and in particular the solenomere tip, and in the femoral processes. While for females, most of the variation in shape occurs in the back of the receptaculum where these male structures engage. As we found for the ears of female spring bushcrickets, the divergence in genital shapes we found in both males and females was much greater than we would expect from neutral divergence alone, suggesting that genital shape is diverging among populations of marri millipedes in response to sexual selection for increased male fertilization success (Sloan *et al*. 2023).

We also conducted population mating crosses using females from Serpentine and males from two different populations: either from Gingin which show relatively little divergence in male genital shape from Serpentine males, or from Manjimup which showed considerable differences in shape to Serpentine males. These crosses revealed that the greater divergence in genital shape among Manjimup males affected their ability to mate, they took longer to insert their gonopods, inserted them multiple times during a mating attempt and, importantly, failed to gain any fertilizations (Wojcieszek & Simmons 2013). These experiments show us that genital divergence among genetically isolated populations can result in reproductive incompatibilities so that although still genetically similar, populations become reproductively isolated, a phenomenon that characterises the first stages in the speciation process.

Antichiropus is a widespread genus of millipedes with many being short range endemics. The genus has speciated extensively across WA, with currently more than 160 species having been recognised (Car *et al.* 2013). These species are mostly identified by variation in the shape of the male secondary genitalia (Fig. 4b). We used microCT imaging again to examine variation in male and female genital shape among 29 species of *Antichiropus* from across WA, finding that male genitalia are evolving more rapidly than female genitalia across this genus. Moreover, our data show that it is the same shape variation that distinguishes between species of *Antichiropus* that distinguishes among populations of *A. variabilis*. That is, species differ in the shape of the solenomere, especially its tip, and in the posterior regions of the female receptaculum. Patterns of incipient speciation in *variabilis* that are driven by sexual selection reflect the macro-evolutionary divergence we see across species in this genus of millipede, illustrating how sexual selection can be instrumental in the origin of *Antichiropus* diversity across WA.

Invertebrate declines and biodiversity conservation

With these four examples of the natural history of WA invertebrates, I hope to have given you a new appreciation of the complex lives and loves of our invertebrate fauna. We are all too aware of the importance of conserving our biodiversity generally, but I would argue that protecting our invertebrates should be at the very core of our conservation efforts. We have seen broadscale global declines

in invertebrate fauna over the last 50 years (Dirzo *et al.* 2014). For insects specifically, IUCN-documented population trends indicate that 33% of insect species are subject to declines in abundance, with some groups suffering more than others (Dirzo *et al.* 2014). The dragonflies and damselflies seem to be faring better than most, while all species of crickets and grasshoppers for which we have data are showing declines in their abundance. The most recent published estimates suggest that globally we are losing 1–2% of our insect fauna per year (Wagner *et al.* 2021).

A number of anthropogenic causes for these declines have been identified. Habitat clearing is a major contributing factor, and the main reason why here in the southwest of WA we are recognised as a biodiversity hotspot. We have cleared >70% of our native vegetation that would have been home to our invertebrate fauna. This habitat loss has been coupled with increased use of pesticides such as neonicotinomides in the expanding agricultural landscapes, which kill not just the targeted crop pests but also other species of insects that provide important ecosystem services. And then there is climate change, which is predicted to see continuing increases in average temperatures, and increasing periods of drought (Harvey *et al.* 2023). There is increasing evidence that short periods of elevated temperature or decreased humidity such as those that would characterise heat waves, have a significant impact on the fertility of male insects, with obvious consequences for reproduction and population persistence (Walsh *et al.* 2019).

The declines in invertebrate abundance warrant immediate action, because invertebrates provide critical ecosystem services that are absolutely necessary for sustaining our broader biodiversity (Harvey *et al.* 2023). Invertebrates such as bees and wasps provide critical pollination services. Thynnine wasps for example, are attracted by sexually mimicking orchids to affect their pollination. Each orchid species has co-evolved with a given species of wasp, creating a unique partnership in which the orchid produces the pheromone used by the female wasp and in so doing dupe the male into collecting and transferring pollen (Phillips *et al.* 2017). Loss of a species of wasp will therefore result in the loss of an orchid species. If the pollination services provided to natural ecosystems is not enough to be of concern, these pollination services are required for around 85% of commercially grown agricultural produce, representing a third of global food supply and valued at $657 billion worldwide and $6 billion in Australia (Klein *et al.* 2007; Allsopp *et al.* 2008). We cannot afford to lose insect pollinators. Insects are also important population regulators of other species. Insect predators and parasitoids, such as the parasitoid fly that attacks Hawaiian crickets, utilise a range of invertebrate hosts, preventing herbivore outbreaks that would otherwise destroy both natural and agricultural landscapes. Species such as millipedes and dung beetles process dead or waste materials from animals and plants, recycling nutrients into the soil while cleaning our terrestrial and aquatic environments. And invertebrates are critical food sources for other organisms, such as amphibians, reptiles, birds, mammals and even our endemic insectivorous plants. Our biodiversity is a house of

cards, supported by insects and other invertebrates. We neglect them at our peril.

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Shorebirds on the Port Kennedy Scientific Park beaches, Western Australia

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Abstract

Port Kennedy Scientific Park is a 708 ha A-class nature reserve set aside in 1971 for the purposes of conservation, scientific research and education. The area represents one of the largest intact coastal environments remaining on the central Swan Coastal Plain, and its conservation values have been documented in the Rockingham Lakes Regional Park Management Plan. Degrading this reserve are the activities of some visitors and their uncontrolled dogs, cars, motorbikes, rubbish dumping and camping. Despite this degradation, 17 migratory and 8 species of resident shorebirds were recorded on the beaches. The most regularly observed migratory shorebirds were the Greater Sand Plover, Ruddy Turnstone, Great Knot, Sanderling and Red-necked Stint, and breeding was recorded once each in the resident Australian Pied Oystercatcher and Red-capped Plover. A checklist and summary of opportunistic observations are provided.

Introduction

Many species of migratory shorebirds are in rapid decline, both in Australia and along their flyways. They need to forage at terrestrial and coastal wetlands to replenish their energy so they can migrate and breed successfully, but they are threatened by the destruction of these habitats and disturbance by people and their livestock, especially in Asia (Birdlife Australia 2023). Habitat destruction and disturbance are also significant problems while in Australia (Birdlife Australia 2016; Fuller *et al*. 2021). The Perth metropolis includes spectacular beaches promoted as some of the best in Australia; due to development, however, meagre protection has been afforded this coastal environment. An exception is the 708 ha Port Kennedy Scientific Park (PKSP), an A-class nature reserve that is the largest intact coastal environment remaining on the Swan Coastal Plain between Fremantle and Mandurah. The birdlife of the wider area has been well-documented (e.g. KRMB 1988; Brooker *et al*. 1995; City of Rockingham 2010), however, apart from an unpublished report (Ninox Wildlife Consulting 1993) very little information has been provided on the PKSP birdlife, particularly the importance of an undeveloped coastline in the Perth metropolis for shorebirds. Of the 54 species of regular migratory and resident shorebirds

documented in Australia (Birdlife Australia 2016) 46% have been recorded on the PKSP beaches. Here I provide a checklist and summary of opportunistic observations and discuss the problems of prohibited recreational activities impacting the conservation value of the reserve for shorebirds.

Survey Area

PKSP is located 48 km south of Perth between the suburbs of Port Kennedy and Secret Harbour, within the City of Rockingham (Fig. 1). It includes two beaches: one in the northwest (NW) fronting Warnbro Sound, ~1.4 km in length, and the other to the southwest (SW) fronting the Indian Ocean, ~4 km in length. The beaches meet at Becher Point (also called Long Point). The PKSP forms part of the Rockingham Lakes Regional Park (RLRP) which comprises a network of environmentally significant lands containing coastal, wetland and upland ecosystems and traverses the unique Rockingham-Becher Plain that includes the Becher Point Wetlands Ramsar Site (Site No. 1048), from the coastal promontories of Cape Peron and Port Kennedy, inland to the wetlands of Lakes Cooloongup and Walyungup (CCWA 2010; Urban Bushland Council 2023).

To emphasise the significance of the area, the PKSP protects a geomorphic feature of international importance for scientific research. This area is one of the youngest formations on the Swan Coastal Plain and provides an example of Holocene sedimentation and stratigraphic evolution. The Rockingham-Becher Plain is globally

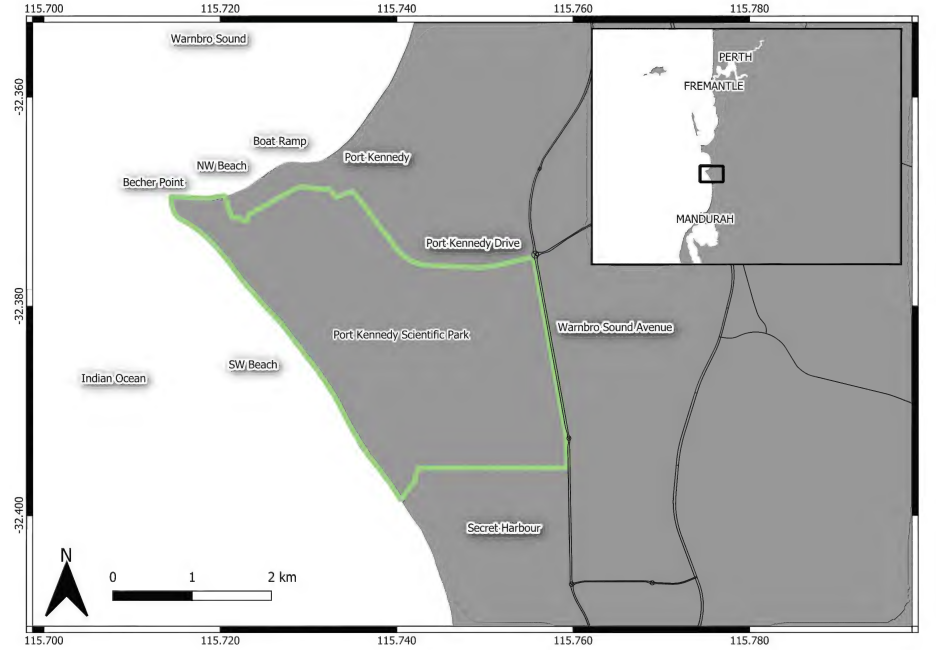

Figure 1. Location of Port Kennedy Scientific Park.

unique and arguably the best example of a consistently developed beach ridge complex in the world (Semeniuk Research Group 1991). The Becher Point Wetlands, which occur in the swales of the ridges, are the only place in Australia that shows the progression of old to young wetlands providing a record of the evolution of coastal wetlands and associated floral assemblages (Semeniuk Research Group 1991). The wetlands also support the critically endangered threatened ecological community sedgelands in Holocene dune swales of the Swan Coastal Plain.

Observations

A total of 17 migratory and 8 species of resident shorebirds were opportunistically recorded during summer by walking along the two beaches between 2015–2022 (Table 1). Observations were made with binoculars and presence was recorded; numbers of individuals were not usually recorded. Not included in the checklist, are a single Bar-tailed x Hudsonian Godwit hybrid seen in November 2020 and Terek Sandpiper in December 2022 which are from ebird (2023). Most shorebirds were observed on the SW beach fronting the ocean, a broader and longer stretch of coastline with more beach wrack than the NW beach fronting Warnbro Sound, which had minimal wrack and where few shorebirds were observed. The importance of beach wrack in providing a feeding resource for shorebirds, particularly migratory species, is well documented (e.g. Campbell 2018; Singor 2018; Singor & Bishop 2022).

The most numerous migratory shorebirds recorded and sometimes over-wintering were the Ruddy Turnstone and Sanderling (Fig. 2), frequently in several separate groups

Figure 2. Feeding groups of (A) Great Knot and (B) Sanderling are regularly observed on the SW beach during summer. Photos: B. Maryan.

of up to 20 birds spread along the coastline, with the former more prevalent where the beach wrack accumulates. The Greater Sand Plover and Great Knot (Fig. 2) were both regularly recorded but in smaller groups of 8–12 birds. The Greater Sand Plover foraged widely across the breadth of the beach from the shoreline to the littoral vegetation. The Red-necked Stint was also regular but in smaller numbers, often singly or in groups of 4–6 birds. The Great Knot has been recorded as late as April at which time their breeding plumage was developing. Occasional records were made of the Grey Plover (singly), Eurasian Whimbrel (singly), Grey-tailed Tattler (1–2 birds), Common Sandpiper (1–2 birds) and Red Knot (small groups of 4–10 birds). The Double-banded Plover was a scarce visitor only seen twice as single birds in April and June 2018, and based

Table 1. Shorebirds recorded on Port Kennedy Scientific Park beaches between 2015–2022. *EPBC Status.

Migratory Shorebirds		**Occurrence**
Grey Plover	*Pluvialis squatarola*	Occasional
Pacific Golden Plover	*Pluvialis fulva*	Scarce
Lesser Sand Plover	*Charadrius mongolus*	Scarce/Endangered*
Greater Sand Plover	*Charadrius leschenaultii*	Regular/Vulnerable*
Double-banded Plover	*Charadrius bicinctus*	Scarce
Bar-tailed Godwit	*Limosa lapponica*	Scarce/Vulnerable*
Eurasian Whimbrel	*Numenius phaeopus*	Occasional
Eastern Curlew	*Numenius madagasariensis*	Scarce/Critically Endangered*
Grey-tailed Tattler	*Tringa brevipes*	Occasional
Common Sandpiper	*Tringa hypoleucos*	Occasional
Ruddy Turnstone	*Arenaria interpres*	Regular
Great Knot	*Calidris tenuirostris*	Regular/Critically Endangered*
Red Knot	*Calidris canutus*	Occasional/Endangered*
Sanderling	*Calidris alba*	Regular
Red-necked Stint	*Calidris ruficollis*	Regular
Sharp-tailed Sandpiper	*Calidris acuminata*	Scarce
Curlew Sandpiper	*Calidris ferruginea*	Scarce/Critically Endangered*
Resident Shorebirds		
Australian Pied Oystercatcher	*Haematopus longirostris*	Regular
Sooty Oystercatcher	*Haematopus fuliginosus*	Scarce
Black-winged Stilt	*Himantopus himantopus*	Occasional
Banded Stilt	*Cladorhynchus leucocephalus*	Occasional
Red-necked Avocet	*Recurvirostra novaehollandiae*	Scarce
Red-capped Plover	*Charadrius ruficapillus*	Regular
Hooded Plover	*Thinornis rubricollis*	Scarce
Beach Stone-curlew	*Esacus magnirostris*	Scarce

on Singor (2016), represents the first records of this species at the PKSP. Only recorded once were the Lesser Sand Plover, Bar-tailed Godwit, Eastern Curlew, Sharp-tailed Sandpiper and Curlew Sandpiper.

The most numerous resident shorebirds were the Red-capped Plover, seen almost all year round with group numbers exceeding 50 birds. Similarly, the Australian Pied Oystercatcher was seen all year round singly or in pairs. These two species were recorded breeding once each on the SW beach, comprising single chicks, which did not survive for long due to predation. The Sooty Oystercatcher was a scarce visitor with only one pair recorded. Occasional small groups (4–6 birds) of Black-winged and Banded Stilts were recorded and a small group of Red-necked Avocet was recorded once.

The groups of Banded Stilt often exceeding 50 birds seen by the author on beaches elsewhere in Warnbro Sound, are possibly resting before flying to and/or from Rottnest Island. The island supports more than 1% of the world's non-breeding population of Banded Stilt on a regular basis (Birdlife International 2023). An immature Hooded Plover was seen in October 2019 and a Beach Stone-curlew in October 2021, both on the NW beach. The Beach Stone-curlew was not recorded by Storr & Johnstone (1988) on the Swan Coastal Plain as it is primarily a resident of undisturbed open beaches across northern and eastern Australia. In recent times there have been regular sightings on Carnac, Garden and Rottnest Islands (Western Australian Bird Notes 2022, 2023), suggesting the PKSP individual flew across from one of these.

Discussion

Australia provides critical habitat for up to two million migratory shorebirds each year (Watkins 1993), but their global decline represents one of the top conservation crises facing birds in the world today. This is mainly attributed to habitat loss; therefore, any stopover sites are crucial for them to rest and refuel during migration, particularly in developed and populated areas with limited suitable habitat. One of the key recognised threats to shorebirds in Australia is disturbance that disrupts their normal activities (Harding *et al.* 2007). The cumulative effect of daily disturbances is unsustainable if birds are unable to increase energy reserves, leading to them abandoning the sites (e.g. Rehfisch *et al.* 1996; Lilleyman *et al.* 2016). In Australia, they are listed as migratory/marine species and protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and are defined as Matters of National Environmental Significance (MNES), while several species recorded on the PKSP beaches are also threatened under the EPBC Act. These include the Vulnerable Greater Sand Plover and Bar-tailed Godwit, Endangered Lesser Sand Plover and Red Knot, and Critically Endangered Eastern Curlew, Great Knot and Curlew Sandpiper. Additionally, migratory shorebirds have been assessed globally using the IUCN Red List categories and criteria based on their national extent and level of threat (International Union for Conservation of Nature 2023). Under the Wildlife Conservation Plan for Migratory Shorebirds, a shorebird site is considered nationally important if it regularly supports 0.1% of an East Asian-Australasian Flyway population

of any migratory shorebird species (Hansen *et al*. 2016). Therefore, it is possible the SW beach of the PKSP meets the flyway population criteria to qualify as a nationally important site for Ruddy Turnstone and Sanderling based on the cumulative value of consistent numbers of these species. Additionally, the regular occurrences of the Greater Sand Plover and Great Knot could also be considered significant.

The PKSP provides a unique natural environment within the Perth metropolis, but despite the significance of this A-class nature reserve as outlined in the RLRP Management Plan (CCWA 2010), there is no interpretive signage anywhere explaining what the land is and why it is protected. Recreational activities, mostly on the weekends and during holiday periods, include the high impact disturbances of uncontrolled dogs, 4WD vehicles and motorbikes. There is also rubbish dumping and camping with fires, the latter activity creating a twofold problem of increased fire risk and damage to native vegetation when harvesting firewood. The substantial dog activity is a major issue on both beaches with largely ignored contrasting requirements. Dogs are not permitted on the NW beach, which is reserved for public swimming, while on the SW beach, they are allowed but must be under control on a leash; however, it is unsuitable to have a dog beach adjacent to a nature reserve.

Most of the PKSP has a perimeter fence combined with large limestone rock barriers and accompanying signage of no unauthorized vehicles; however, in certain locations the fence has either been pushed over by 4WD vehicles or drivers find gaps to gain access to the beaches. It is virtually impossible to prevent motorbikes from entering the reserve. On some occasions, particularly on the SW beach where most shorebird activity occurs, there can be several parked vehicles and motorbike riding at the same time. Additionally, other disturbances include pedestrian walkers, anglers, jet skis, boat traffic and, amongst the most peculiar activity seen, two people hitting golf balls on the NW beach into the water. Also, as indicated by their tracks and observations of them during the day on the beaches there is an abundance of red foxes, and certainly at night domestic cats would visit the reserve from nearby residences.

Apart from the five regular migratory shorebird species, the remainder consist of occasional or scarce records possibly due to the above level of disturbance on the beaches, restricting the birds to only a temporary stopover before quickly flying to less-disturbed feeding sites. The levels of disturbance have noticeably contributed to the reduction in numbers and length of the stopover of migratory shorebirds at Woodman Point (Singor 2021). A recent attempt by Fairy Terns to nest at Becher Point in December 2020 was abandoned due to disturbance by people and their dogs, despite the efforts made by the City of Rockingham staff installing barriers and signage. Overall, the mitigation of these activities by the jointly managed authorities of the City of Rockingham (NW beach only) and the Department of Biodiversity, Conservation and Attractions (DBCA) is going to be difficult, but currently it is effectively non-existent, particularly on weekends and during holiday periods when

activities are greatest, although constraints on funding and resources play a major role in determining priorities.

The scale of the problems at the PKSP is primarily caused by its convenient location providing opportunities for the "use and abuse" approach by irresponsible people. However, measures such as improved surveillance and increased fines for unauthorized vehicles, heightened presence by authority staff, as well as interpretive signage in relation to the reserve and informing people, particularly dog owners, about the impacts of their pets, will minimize the degradation and disturbance to shorebirds. The accumulation of beach wrack seasonally varies on the SW beach providing an important resource for feeding shorebirds but seems to be most prolific during the winter months leading up to summer when the migratory shorebirds arrive. From a management perspective, minimising disturbance by excluding people and their pets on sections of beaches allows shorebirds a refuge in a highly developed and populated area (e.g. Petel & Bunce 2012; Dayer *et al*. 2022). Otherwise, if the necessary resources cannot be acquired to protect the conservation values of an A-class nature reserve, the purpose of the RLRP management plan in providing the key framework for this to occur becomes obsolete and the reserve could be downgraded to reflect the lack of protection. By contrast, at the opposite end of Warnbro Sound, the conservation values of the A-class nature reserve Penguin Island are adequately managed as part of the Shoalwater Islands Marine Park, otherwise, it would have met a similar fate of anthropogenic degradation.

List of Abbreviations

CCWA – Conservation Commission of Western Australia

KRMB – Kwinana, Rockingham and Mandurah Branch of the WA Naturalists' Club

NW – Northwest

PKSP – Port Kennedy Scientific Park

RLRP – Rockingham Lakes Regional Park

SW – Southwest

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Further records and an unusual nesting site of the recently introduced bee *Pseudoanthidium repetitum* (Schulz, 1906) (Hymenoptera: Megachilidae) in Western Australia

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Abstract

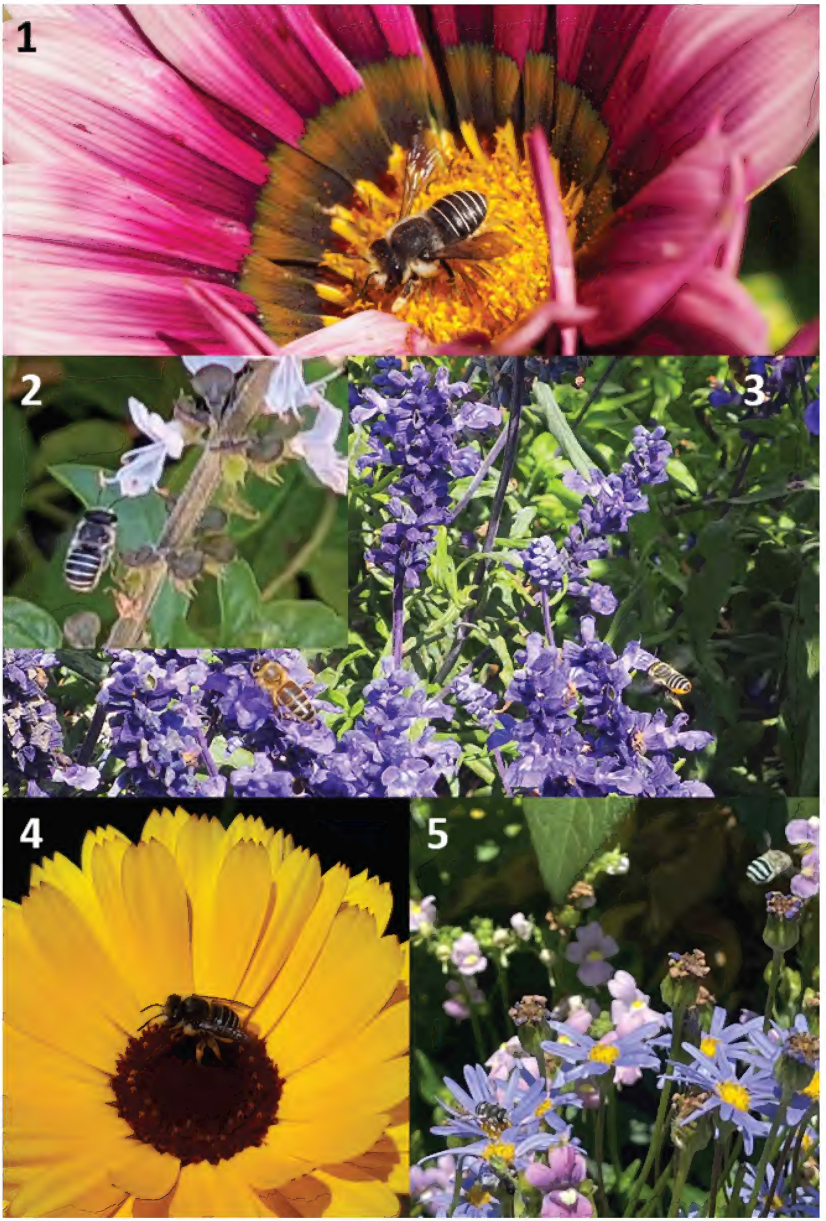
The African carder bee *Pseudoanthidium (Immanthidium) repetitum* (Hymenoptera: Megachilidae) is introduced to Australia. First recorded in Australia in 2000 in south-east Queensland, it subsequently spread down the east coast of Australia. In 2019, it was first recorded in Western Australia. Here, I report further occurrences of this species, as evidence that it has expanded its distribution. I also report a novel nesting habitat – small watering cans in a garden mobile ornament. I provide an updated description of the flowering resources it has been observed foraging on. As with the first observations, these new records were brought to my attention through a member on the citizen science Facebook group 'Bees in the burbs', underscoring the value of community bee groups in understanding the distribution, spread and behaviour of species. Thus far it appears to be confined to residential gardens, suggesting it is associated with anthropogenic garden habitats.

Keywords: alien species, Australia, bee, carder bee, citizen science, introduced species

Introduction

Pseudoanthidium (Immanthidium) repetitum (Schulz, 1906) (Hymenoptera: Megachilidae) (Fig. 1), the African carder bee, is native to South Africa. It is one of the few non-*Apis* introduced species in Australia. *Pseudoanthidium repetitum* was first documented in Australia in Brisbane, south-east Queensland in 2000 (Burwell & King 2000) and subsequently expanded down the east coast (Baumann *et al.* 2016). The species was recorded in south-western Australia at three coastal locations in the Halls Head/Mandurah region (Prendergast 2020).

While it is superficially similar to native megachilids, especially those in the subgenus *Eutricharaea, P. repetitum* can be readily distinguished from megachilids by having white integumental bands rather than hair



Figures 1–5. *Pseudoanthidium (Immanthidium) repetitum*: **1.** Female foraging on *Gazania* at the new Halls Head location, November 2020. Photo: Z. Elliot. **2.** Female foraging on basil at Australind. Photo: Z. Elliot. **3.** *Apis mellifera* and *P. repetitum* foraging together on a patch of *Salvia* at Halls Head. Photo: K. Prendergast. **4.** *P. repetitum* in South Bunbury. Photo: K. Allen. **5.** *P. repetitum* and *Amegilla chlorocyanea* foraging in the same patch of flowers in Halls Head. Photo: R. Taylor.

bands on the abdomen (see Fig. 5 in Prendergast 2020). Unlike solitary megachilids, *P. repetitum* constructs communal nests in cavities, including human-made ones like electrical meter boxes and wooden boxes. Cells are comprised of plant fibres scraped off leaves or stems by the female bees with their mandible. The hairs are then rolled together in a mass resembling cotton balls (Litman 2012). Based on its morphological features and nesting habits, *P. repetitum* is therefore readily differentiated from other native bees. There is one other introduced 'carder bee', *Anthidium manicatum* (Linnaeus, 1758), documented in Victoria in 2020 (Walker *et al.* 2020). *Anthidium manicatum* is readily distinguished from *P. repetitium* by having yellow integumental bands that are broken medially on the abdomen.

As noted in Prendergast (2020), ongoing monitoring is required to determine if *P. repetitum* establishes in Western Australia and to track its distribution and abundance. While some introduced species fail to establish, others can be 'sleeper' species, and after a lag phase, increase in numbers to become an environmental or economic pest (Crooks 2005).

Here, I document two new localities of the bee and also describe the flower species it forages on, provide an update on its records at previous locations and describe a novel nesting substrate for *P. repetitum.*

Methods

Identifications were made by the author with reference to Litman *et al.* (2016). To respect the requests of the homeowners, no specimens were collected, however, high-resolution photographs were taken to confirm its identity. This species is highly distinctive, being the only species in the genus *Pseudoanthidium* in Australia.

Results

The new records of *P. repetitum* were from Halls Head, close to previous records, and two new locations, in South Bunbury and Australind (Fig. 6). These last two locations are approximately 110 km south of previous records. All new records were a result from photos being posted by members on my Facebook group 'The Buzz on Wild Bees' (previously 'Bees in the burbs') which I recognised as being *P. repetitum.*

South Bunbury 2020

The South Bunbury observations were made in April and late November 2020. K. Allen contacted me in December with photos that I was able to confirm were of *P. repetitum* (Fig. 4). No nests were found and the species was not observed subsequently. *Megachile (Eutricharaea)* sp. was observed foraging concurrently.

Halls Head 2021

Another record was made at Halls Head, Mandurah, close to those reported in 2020. These records by R. Taylor were posted on 'The Buzz on Wild Bees' in early November 2021 and had been observed the previous year as well. The bees were foraging in the backyard garden which was comprised of predominantly exotic horticultural plants in high density. Numerous introduced *Apis mellifera* Linnaeus, as well as native *Amegilla (Notomegilla) chlorocyanea* Cockerell,

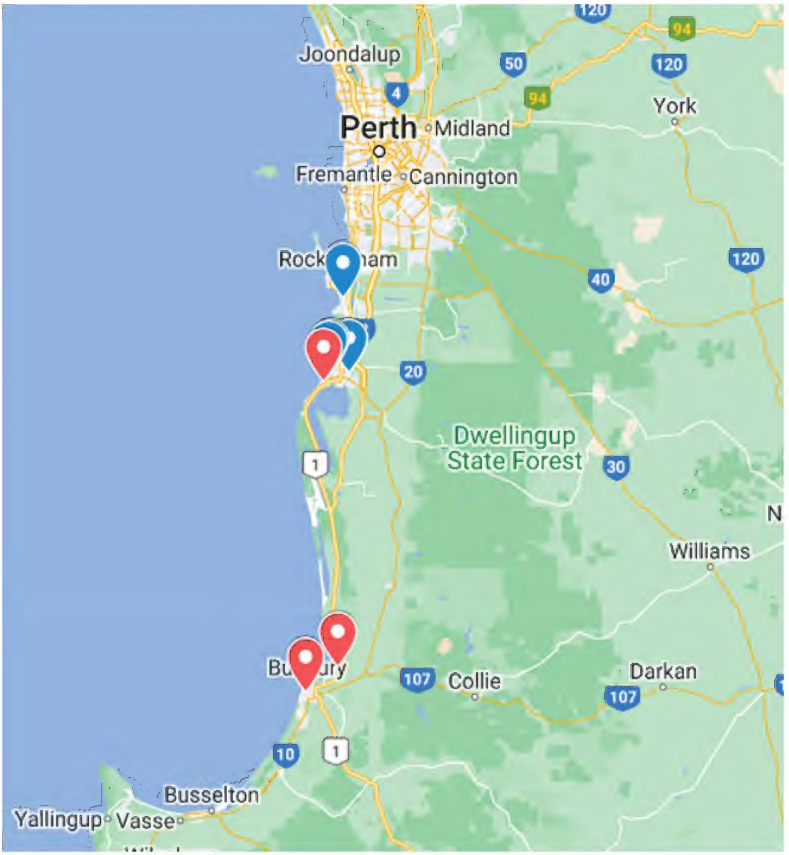


Figure 6. Records of *Pseudoanthidium (Immanthidium) repetitum* in Western Australia. Previous records in blue; new records in red.

Megachile (Eutricharaea) sp. and flies were also foraging (Figs. 3, 5).

Unusual nesting location

Nests were located in four of eight small metal ornamental watering cans that were part of an outdoor garden mobile hanging under the eaves (Figs. 7, 8). I visited the location on 17 November 2021 and confirmed the identity of the bee (Fig. 1) and the nests. The watering can ornaments were suspended ~1 m off the ground and measured approximately 5 cm wide x 10 cm deep. Each ornamental watering can contained the characteristic 'cotton ball' nesting material and a number of brood cells, from some of which bees had eclosed.

Australind 2022

The most recent record was posted on 'The Buzz on Wild Bees' by Z. Elliot. Her photos, taken on 7 January 2022, showed a female *P. repetitum* foraging on perennial basil *Ocimum basilicum* (Fig. 2). Z. Elliot informed me that native bees also frequented her garden.

Figures 7–8. *Pseudoanthidium (Immanthidium) repetitum* nest in the garden mobile made of ornamental watering cans. **7.** Entire mobile and location. Photo: K. Prendergast. **8.** Close-up of 'carder' nest inside one of the watering cans. Photo: K. Prendergast.

Previous Halls Head location

The species has not been observed in the garden at Halls Head where it was recorded the previous year in 2020 (Prendergast 2020), despite searching by the homeowner in her garden and asking owners in the neighbourhood to look out for it (Kat Lowry, pers. comm. 2021).

Host plant records

In Bunbury, *P. repetitum* was observed foraging on yellow *Calendula* and pink *Cosmos* (both Asteraceae). In Halls Head, the species was observed foraging on pale purple *Nemesia fruticans, Antirrhinum majus* (both Plantaginaceae), pink-white and yellow-purple *Gazania,* white-purple *Osteospermum,* mauve *Felicia amelloides* (Asteraceae) and purple *Salvia farinacea* (Lamiaceae). At Australind, it was observed foraging on white perennial basil *Ocimum basilicum* (Lamiaceae) and curry tree *Murraya koenigii* (Meliaceae).

Discussion

These new records indicate it is likely *P. repetitum* has established in Western Australia, although it remains rare. The new location in Bunbury suggests it may have spread; however, given Bunbury is a port city, introduction via ship cannot be ruled out.

Pseudoanthidium repetitum appears to be confined to garden habitats and exotic flowers, contrasting with native bee species in southwest Western Australia (Prendergast *et al.* 2022; Prendergast 2023). Most native bees in Western Australia have not been observed foraging on the flower species *P. repetitium* has been documented foraging on. Furthermore, even generalist species that can forage on

these plant species (Prendergast & Ollerton 2021) have been observed coexisting with *P. repetitum* (e.g. Fig. 5, see also Prendergast 2020). Consequently, adverse impacts on native species from resource competition *with P. repetitum* appear unlikely (Prendergast *et al*. 2021). Although its preference for exotic flora suggests it may aid in the spread of weeds, this is also unlikely because it is confined to garden habitats.

The new nesting location demonstrates the adaptability of this species to exploit anthropogenic structures as a nesting substrate. Although it made its nests in a pre-existing garden ornament, imported garden ornaments may have been the route by which *P. repetitum* entered Australia and/or Western Australia.

These further observations have also identified the flowering species visited by *P. repetitum* locally. Given the low density of this species, and that the flowers *P. repetitum* visits are exotics, it is unlikely that this species represents a major source of competition for native bees, most of which prefer Australian native plants (Prendergast 2023).

These additional records demonstrate the utility of community citizen science groups run by scientists for documenting the distribution, phenology and behaviour of species, including introduced species.

Acknowledgements

I would like to thank Rachel Taylor, Kristen Allen and Zadia Elliot for informing me of further observations of these bees in their gardens, as well as Kat Lowry for continuing to look for *P. repetitum* in her garden.

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Snapshot survey of the fish and benthic macroinvertebrate fauna of Hill Inlet, Western Australia

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Abstract

This study provides the first quantitative information on the fish and benthic macroinvertebrate faunas of Hill Inlet, the northern-most estuary in temperate south-western Australia. Sampling was conducted in June 2019, when water levels were very high and the bar at the mouth of the estuary was intact. Surface salinities were low and declined in an upstream direction, but a marked halocline was present at most sites, resulting in pronounced hypoxia. Five fish and ten invertebrate species (primarily polychaetes, molluscs and crustaceans) were recorded. The low number of species found in Hill Inlet, relative to other estuaries in the region, was likely caused by the environmental conditions present at the time of sampling.

Introduction

Estuaries are crucial habitats providing a range of ecosystem services including the provision of nursey areas for a variety of fish and crustacean species, and are also widely used by humans (Barbier *et al.* 2011; Potter *et al.* 2015a). In recent years there has been growing recognition that the physical and biotic characteristics of estuaries with a small tidal range (i.e. microtidal; < 2 m), such as those in south-western Australia, are markedly different from those systems with a larger tidal range (Tweedley *et al.* 2014a, 2016a; Rose *et al.* 2019). From a faunal perspective, the shallow waters of microtidal systems are dominated by species capable of completing their life cycle within estuaries (e.g. atherinids and gobiids), with fish in deeper waters generally comprising marine estuarine-opportunists that use the estuary as a nursery area (Chuwen *et al.* 2009; Hoeksema *et al.* 2009, 2023). The benthic macroinvertebrate faunas of microtidal estuaries also differ from macrotidal systems, lacking large suspension feeders and predominantly comprising small deposit-feeding species, whilst also harbouring insect larvae (Tweedley *et al.* 2016a, 2016b). Given their limited tidal water exchange and highly seasonal rainfall, south-western Australian estuaries are particularly vulnerable to degradation and climate change and

thus require regular monitoring and careful management (Hallett *et al.* 2018; Warwick *et al.* 2018). While much focus has been placed on understanding the larger systems located near population centres, such as Perth, Mandurah and Bunbury (e.g. Veale *et al.* 2014; Potter *et al.* 2016; Valesini *et al.* 2018), less focus has been placed on smaller, more regional estuaries (Tweedley *et al.* 2017a, 2018).

Hill Inlet (30°23'17.2"S; 115°03'09.3"E) is a small (0.06 km^2) wave-dominated system located ~200 km north of Perth, in Western Australia. It is 'riverine' in geomorphology and lies in Pleistocene sediments towards the northern extent of the Swan Coastal Plain (Hodgkin & Hesp 1998). The estuary and its catchment are located in a Mediterranean climatic region, which is characterised by warm to hot, dry summers and mild to cool, wet winters, with 80% of annual rainfall occurring between May and October (Hallett *et al.* 2018). It is fed by the ~80 km long Hill River, with a catchment area of 2,800 km^2 and an average annual flow of 5,250 ML (Brearley 2005). This river is unique in this part of Western Australia, as it is the only one that 'meets' the ocean along the 270 km coastline between Dongara in the north (29°15'3.6"S, 114°56'2.4"E) and Guilderton in the south (31°20'33.36"S, 115°29'34.8"E), with other rivers terminating in small fresh or saline lakes and swamps (Pen 1999).

Surveys of Hill Inlet in the 1960s found that water in the Hill River was brackish due to secondary salinisation, however, it is thought that prior to the clearing of 25% of the catchment for agricultural purposes, it was a freshwater system (Brearley 2005). Like many of the estuaries in south-western Australia, Hill Inlet does not maintain a permanent connection with the ocean, with longshore and onshore transport of sand forming a bar at the mouth of the estuary (Brearley 2005; Hoeksema *et al.* 2018). This sand bar is reported to break each year, i.e. it is classified as a seasonally-open estuary *sensu* Hodgkin and Hesp (1998), the timing of which is related to the occurrence of the first heavy and consistent rain episodes. The bar typically remains open for a few days or weeks, depending on the amount of freshwater within the estuary when the bar breaks, which scours away sand (Brearley 2005).

In a classification of the 'condition' of 979 estuaries across Australia, based on the extent of human influence on catchment land use, hydrology, tidal regime, floodplain and estuary use, pests and weeds and estuarine ecology, Hill River was assigned the status of 'modified' (Commonwealth of Australia 2002). This system, together with Toby Inlet and the Margaret River Estuary, were the only estuaries on the west coast of south-western Australia not to be rated as 'extensively modified' (Tweedley *et al.* 2017b). However, Hill Inlet and its catchment are being increasingly threatened by uncontrolled access by off-road vehicles, which, elsewhere have been shown to have a range of impacts. These include accelerating dune erosion, damaging vegetation and crushing benthic invertebrates such as crabs, isopods and bivalves (Davenport & Davenport 2006; Sheppard *et al.* 2009). The severity of the impacts of off-road vehicles led to South African authorities banning such vehicles from large stretches of the KwaZulu-Natal coastline (Celliers *et al.* 2004). Off-road vehicles have also had indirect impacts by providing recreational fishers with access to sites that may have been

previously inaccessible. Given the very small size of Hill Inlet, it is possible that if recreational fishing effort increased markedly, fish populations could decline. For example, changes made to off-road vehicle access in South Africa led to a marked increase in recreational fishing in the Sundays Estuary and a decline in the abundance of recreationally-targeted fish species (Cowley *et al.* 2013).

The aim of this study was to provide the first quantitative snapshot of the fish and benthic macroinvertebrate fauna of Hill Inlet, including the detection of any introduced species. These data could then be used in management plans for the estuary and form a benchmark against which future changes could be evaluated.

Materials and methods

Sampling regime

All sampling was conducted during two days in June 2019 (austral winter), when the bar at the estuary mouth was closed to the ocean (Fig. 1). Water levels were higher than expected (i.e. based on an available satellite image taken in August 2018) and the surrounding salt marsh had become inundated (Fig. 1). Fish in shallow waters (<1.5 m deep) were sampled using a seine net 21.5 m long, 1.5 m deep, consisting of two 10 m long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m long bunt made of 3 mm mesh and swept an area of ~116 m^2. High water levels (i.e. greater than the depth of the net), prevented systematic sampling of the entire estuary and so sampling was conducted only at shallower sites where the net would work effectively (Fig. 1). After capture, all fish from seine nets were identified to species using the keys in Goman *et al.* (2008) and returned to the water alive

Fish in deeper waters (>1.5 m) were sampled at three sites in each region of the estuary (i.e. lower and upper estuary; Fig. 1) using sunken, composite, multifilament gill nets deployed from a boat. Each gill net was 160 m in length and 2 m in height and comprised eight 20 m long panels of different stretched mesh size (35, 51, 63, 76, 89, 102, 115 or 127 mm). This was the maximum number of nets that could be deployed without them overlapping. Nets were set for 1 h after sunset to allow each captured fish to be removed from the net, identified, measured and returned to the water alive. Abundances of each species were recorded as catch rate h^{-1}. All work was carried out in accordance with Murdoch University Animal Ethics Permit R2987/17 and Department of Primary Industries and Regional Development Exemption #2987.

Each fish species recorded was assigned to a life-cycle guild according to the way in which it uses estuaries (Potter *et al.* 2015b). These guilds are based on the location of spawning and for which part and the duration of its life-cycle a species utilises estuaries (Whitfield *et al.* 2022). Definitions of the two guilds relevant to the current study are as follows. Marine estuarine-opportunist: i.e. species that spawn at sea and regularly enter estuaries in substantial numbers, particularly as juveniles, but can also use coastal marine waters as alternative nursery areas. Solely estuarine: i.e. species typically found only in estuaries and individuals complete their life cycles in these systems.

Benthic macroinvertebrates were sampled at 10 sites spread along the

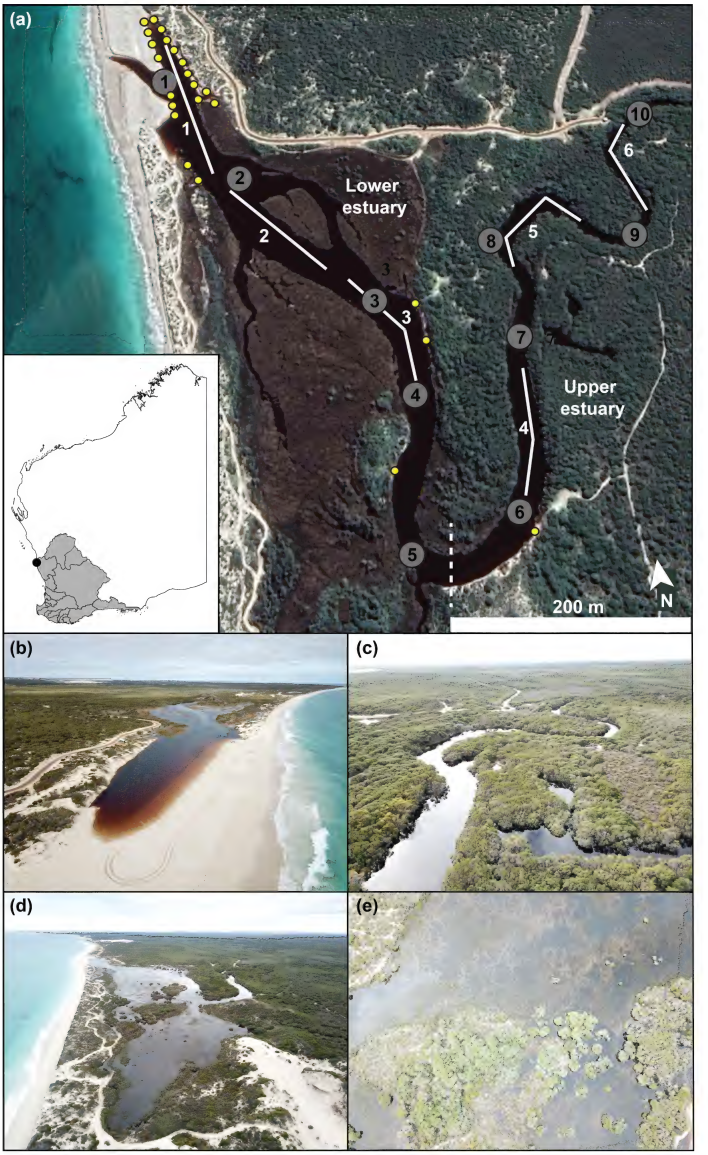

Figure 1. Satellite image of Hill Inlet taken in August 2018 showing (a) sites where seine nets (yellow circles), gill nets (white lines) and Ekman grab (grey circles) samples were collected. Note the water levels and lack of inundation of the surrounding salt marsh. Dashed white line denotes the division between the lower and upper estuary. The location of Hill Inlet in Western Australia is denoted by the black circle, grey shading shows the extent of the south-west drainage division. Photographs showing (b) lower and (c) upper regions of Hill Inlet and (d and e) extent of the flooding of the surrounding salt marsh in June 2019. Satellite images provided by Google and CNES/Astrium.

central longitudinal axis of the estuary using an Ekman grab (Wildlife Supply Company, Florida, U.S.A.) operated from a boat, with five sites located in each of the lower and upper estuary (Fig. 1a). The grab collected sediment from an area of 225 cm^2 and sampled to a depth of 15 cm. Each sediment sample was wet-sieved through a 500 μm mesh in the field and preserved in a 5% formalin mixture buffered in estuary water. After a week the sediment was re-sieved and transferred to 70% ethanol. All invertebrates found in a sample were removed from the sediment retained on the mesh and identified to the lowest possible taxonomic level under a dissecting microscope using a range of interactive (e.g. POLiKEY) and taxonomic keys (e.g. Hutchings & Murray 1984; Wells 1984; Davis & Christidis 1997).

Water temperature (°C), salinity and dissolved oxygen concentration (mg L^{-1}) were measured close to the surface and bottom of the water column at each site where benthic macroinvertebrate samples were collected using a Yellow Springs Instrument 556 water quality meter (Yellow Springs Instrument, Ohio, U.S.A.).

Statistical analyses

As most of the samples collected from the seine net contained no fish (i.e. 20 of 23 samples), these data were not subjected to any statistical analyses. All univariate and multivariate statistical analyses were performed using SPSS v24 and PRIMER v7 (Clarke & Gorley 2015), respectively.

The DIVERSE routine was used to calculate the number of species and total catch rate (fish h^{-1}) in each gill net sample, with the latter variable square-root transformed to meet the assumption of homogeneity of variance. Each variable was subjected to an Analysis of Variance (ANOVA) test to determine whether it differed significantly ($P < 0.05$) between regions (lower vs upper estuary). As only three gill nets were able to be deployed in each region and a minimum of four samples are required for robust multivariate analysis, these faunal composition data were not analysed statistically but explored visually. To this end, the abundances of each species in each sample were square-root transformed and used to construct a Bray-Curtis resemblance matrix. This was used to construct a non-metric Multidimensional Scaling ordination plot. The transformed abundances of each species in each sample were used to produce a shade plot. This plot is a simple visualisation of the frequency matrix, where a white space for a species demonstrates that it was never collected, while the intensity of grey-scale shading is linearly proportional to its abundance (Clarke *et al.* 2014).

Data from the five replicate Ekman grab samples from each region were used to construct a data matrix of the number of each benthic invertebrate species (individuals 225 cm^{-2}). This matrix was subjected to the DIVERSE, ANOVA, nMDS and shade plot procedures described for the gill net samples, only with the addition of a one-way Analysis of Similarities (ANOSIM) test to test for difference in the faunal composition between the two regions.

Results and discussion

Water quality

Water temperature at the surface declined in an upstream direction

from 15.3–13.6°C, while values at the bottom were consistent throughout the estuary (17.2°C±0.2 SE), except at the three most downstream sites, where they were lower (15.3–16.4°C; Fig. 2a). Surface salinity declined in an upstream direction from almost 12 near the bar at the mouth of the estuary to < 3 at the most upstream site, ~1.5 km away (Fig. 2b). Salinity was always greater at the bottom of the water column than the surface, except for Site 1 where bottom salinities were reduced (~12), and there was no conspicuous longitudinal change (mean = 26.7±1.0 SE) in bottom salinity from sites 2 to 10.

The oligohaline surface waters were caused by Hill Inlet experiencing a Mediterranean climate, where 80% of rainfall occurs between May and September (Hallett *et al.* 2018). The estuary only received its first discharge (76 ML) from the Hill River in 2019 five days before sampling began, which was the first freshwater discharge for more than 200 d (preceded by an input of 0.003 ML in November 2018; DWER 2021). The recent discharge increased water heights by 1 m over the surface area of the estuary, lowered salinity in the surface waters and causing pronounced inundation of the surrounding salt marsh. However, this flow was not sufficient to raise water levels enough to breach the sand bar at the mouth of the estuary (Fig. 1b-e), which would have increased salinity due to seawater intrusion. The bar did breach, however, several days after sampling was completed.

The pronounced vertical halocline at most sites likely caused the hypoxic conditions (<2 mg L^{-1}) present throughout most of the bottom waters (Fig. 2c). In contrast, oxic concentrations (i.e. 6.4–8.7 mg L^{-1}) were recorded in the surface waters of each site (Fig. 2c).

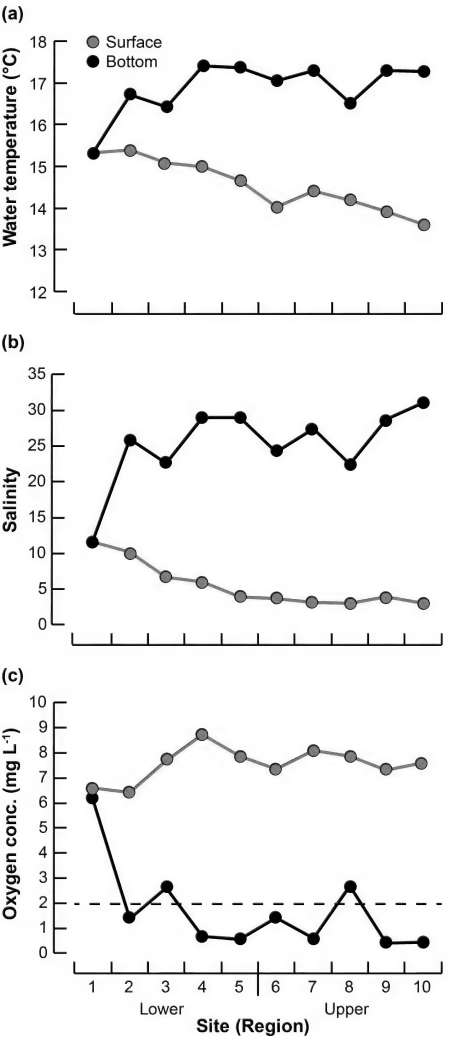

Figure 2. (a) Water temperature (°C), (b) salinity and (c) dissolved oxygen concentration (mg L^{-1}) in the surface (grey line) and bottom (black line) of the water column at each site in Hill Inlet in June 2019. The dashed line in (c) denotes hypoxic conditions (<2 mg L^{-1}).

Fish fauna in shallow waters

Only four fish (two *Acanthopagrus butcheri* and two *Pseudogobius olorum*) were collected from the 23 seine net samples covering an area of ~2,668 m^2, i.e. an average of one fish per ~667 m^2. This density is the lowest recorded in sampling of any estuary in south-western Australia conducted using a 21.5 m seine net (Tweedley 2011) and likely reflects the fact that water levels were at close to their peak before the bar would breach naturally. Under such conditions fish were able to move into the surrounding inundated salt marsh areas (Fig. 1d,e), which were too deep (> 2 m) to be sampled effectively using the seine net. A similar situation was reported by Tweedley *et al.* (2014b) in the Vasse-Wonnerup Estuary where densities of fish were only 20–30 per 100 m^2 during winter, when the surrounding salt marsh was inundated, but increased to ~800 per 100 m^2 on average during spring and summer when water levels were much lower.

Aside from the low density of fish, it was striking that no atherinids were collected by seine netting. Individuals from this family are ubiquitous in south-western Australian estuaries and, together with gobies, can represent up to 99% of all fish recorded in shallow waters (Hoeksema *et al.* 2009; Hogan-West *et al.* 2019). Given their wide tolerances for salinity and presence in high abundances in all estuaries in the region (Valesini *et al.* 2009; Tweedley *et al.* 2019), it is hypothesised that their absence in the current study was related to the elevated water levels and the movement of these individuals into the inundated salt marsh. Furthermore, as the deeper waters were hypoxic, moving to shallower, more oxygenated waters would be advantageous (Poh *et al.*2019). Moreover, the structural complexity provided by the surrounding flooded marsh would limit predation from larger piscivorous fish (Humphries *et al.* 1992), such as the pomatomid *Pomatomus saltatrix* (see below). Both fish species recorded in these shallow waters are solely estuarine species, able to complete their lifecycle within the estuary (Beatty *et al.* 2018; Hogan-West *et al.* 2019). These observations are similar to other studies that have found a trend for members of the solely estuarine guild to dominate the fish faunas of systems that do not maintain a permanently-open connection to the ocean (Hoeksema *et al.* 2009; Tweedley *et al.* 2016a).

Fish fauna in deeper waters

Gill netting in the deeper waters of Hill Inlet yielded 344 fish, representing four species and three families (Table 1). The Mugilidae was the only family to comprise two species (*Aldrichetta forsteri* and *Mugil cephalus*). In contrast to the fish collected in shallow waters, only one of the species caught in deeper waters is able to spawn in estuaries (i.e. *A. butcheri*), with the remaining three species all being marine estuarine-opportunists and that use the estuary as a nursery area. A moderate size range (> 170 mm total length) of individuals from each species, except *P. saltatrix* were recorded (Table 1), suggesting that multiple ages classes of these species were present in Hill Inlet (Chubb *et al.* 1981; Sarre & Potter 2000). *Acanthopagrus butcheri* and the two species of mugilid, comprised the vast majority of individuals (99%), which is fairly common in small estuaries on the west coast of Western Australia (Tweedley *et al.* 2018, Cottingham *et al.* 2019; Krispyn *et al.* 2021).

Table 1. Mean catch rate (h^{-1}; Cr), standard error (SE), percentage contributions to the total catch (%), ranking by contribution (R), mean total length (L, mm) and length range (Lr) of each fish species caught by gill nets in the deeper waters of Hill Inlet in June 2019. The estuarine usage functional group (EUFG) for each species is provided (E, solely estuarine; MEO, marine estuarine-opportunist). Species ranked by total number of fish caught (n).

Scientific name	Family	EUFG	n	Cr	SE	%	R	L	Lr
Mugil cephalus	Mugilidae	MEO	167	27.83	6.51	48.55	1	292	120-400
Acanthopagrus butcheri	Sparidae	E	140	23.33	5.25	40.70	2	196	130-300
Aldrichetta forsteri	Mugilidae	MEO	35	5.83	2.25	10.17	3	279	155-500
Pomatomus saltatrix	Pomatomidae	MEO	2	0.33	0.00	0.58	4	360	350-370

The lack of common species found in nearby estuaries, such as the terapontids *Amniataba caudavittata* and *Helotes octolineatus*, the sparid *Rhabdosargus sarba* and the sillaginids *Sillago schomburgkii* and *Sillaginodes punctata,* likely reflects the limited number of gill net samples collected at one time of year and that the bar at the mouth of the estuary was closed and likely had been for some time, preventing their immigration into the estuary from the ocean. In Toby Inlet, a small estuary located ~400 km south of Hill Inlet, the number of species recorded from 16 gill net samples increased from four when the bar was closed to 12 when the bar was open, with the 'additional' species all being regarded as marine, i.e. marine estuarine-opportunists and marine stragglers (Tweedley *et al.* 2018).

No introduced fish species were recorded in Hill Inlet despite Goldfish (*Carassius auratus*) and the Mozambique Tilapia (*Oreochromis mossambicus*) having been recorded in the Moore River to the south and Chapman River to the north, respectively (Morgan *et al.* 2004). As both species are able to survive in saline waters (Whitfield *et al.* 2006; Beatty *et al.* 2017), there is value to being alert to the presence of these species in the future.

The mean number of fish species in deeper waters differed significantly among regions ($F_{1, 1} = 16.00$, $P = 0.016$) being significantly greater in the lower (3.3±0.3 SE) than upper (2.0±0 SE) estuary. While more fish were caught in the lower than upper region on average (70±3 SE vs 45±17 fish h^{-1}), the mean catch rate did not differ significantly between regions ($F_{1, 1} = 1.84$, $P = 0.246$). This was due to the large variability among the samples from the upper estuary with catches ranging from 12–68 fish h^{-1}.

When the faunal composition data were visualised using nMDS, there was clear separation between the points representing samples from each region, with samples from the upper estuary all located on the right of the nMDS and those from the lower estuary on the left (Fig. 3). While *M. cephalus* and *A. butcheri* dominated catches at all sites, the difference between regions was due to *P. saltatrix* and *A. forsteri* being found only in the lower region (Fig. 4). This trend also accounts for the

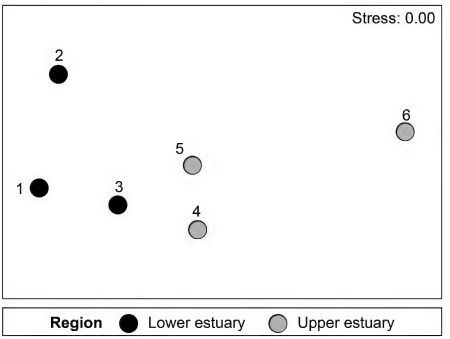

Figure 3. Two-dimensional nMDS ordination plot of the catch rate (h^{-1}) of each fish species caught in gill nets at each site in the deeper waters of the Hill Inlet in June 2019.

number of species recorded declining from four at the bar, to three in the remaining sites in the lower estuary and two at each site in the upper estuary. The spatial distribution of those species reflects their life-history characteristics. Thus, *A. butcheri* is a solely estuarine species, which resides in upper reaches and is very euryhaline (Sarre & Potter 2000). Although *M. cephalus* is a marine species, when present in estuaries, individuals are most typically abundant in upstream regions (Chubb *et al.* 1981; Chuwen 2009). In contrast, larger *P. saltatrix* are typically found in the more saline conditions of the lower reaches of estuaries (Loneragan *et al.* 1989). In this study, while more saline conditions were found in the deeper waters of the upper estuary, these individuals may be responding to cues of marine water seeping through the bar and preparing to leave the estuary immediately upon the bar breaking, which occurred several days after sampling was conducted.

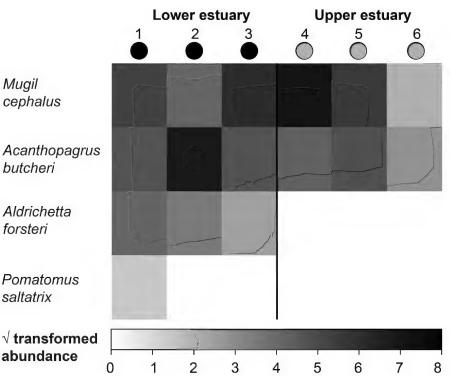

Figure 4. Shade plot of the square-root transformed catch rate (h^{-1}) of each fish species caught in gill nets in the deeper waters of each site in Hill Inlet in June 2019.

Benthic macroinvertebrates

A total of 631 benthic macroinvertebrates were recorded in the 10 Ekman grab samples from Hill Inlet (Table 2). These invertebrates comprised 10 species from four phyla. The groups of taxa represented by the most species were the molluscs and polychaetes, with three and two species, respectively (Table 2). The five most abundant species each contributed > 5% to the total number of individuals, and together comprised 97% of all invertebrates. Among these, the polychaete *Capitella capitata,* bivalve mollusc *Fluviolanatus subtorta* and crustacean Ostracoda sp. were the most abundant taxa (Table 2). The dominance of polychaetes, molluscs and crustaceans in Hill Inlet is typical for estuaries both in south-western Australia and more generally around the world (Tweedley *et al.* 2014a, 2015). Only two individuals from two insect species (larvae of Culicidae sp. and Chronomid sp.) were collected from Hill Inlet (Table 2). This contrasts with Toby Inlet and the Vasse-Wonnerup, which are similar to Hill Inlet, i.e.

Table 2. Mean density (100 cm^{-2}; D), standard error (SE), percentage contributions to the total catch (%C) and ranking based on abundance (R) of each benthic macroinvertebrate species recorded in Ekman grab samples from the Hill Inlet in June 2019. Species ranked by total number of individuals caught (n). The broad taxonomic group (Group) to which each species belongs is also provided.

Species	Group	n	D	SE	%	C%	R
Capitella capitata	Polychaete	297	13.20	5.08	47.07	47.07	1
Fluviolanatus subtorta	Bivalve	131	5.82	2.14	20.76	67.83	2
Ostracoda sp.	Crustacean	95	4.22	7.06	15.06	82.88	3
Arthritica semen	Bivalve	52	2.31	0.10	8.24	91.13	4
Corophium minor	Crustacean	36	1.60	0.10	5.71	96.83	5
Nematoda spp.	Nematode	11	0.49	21.28	1.74	98.57	6
Soletellina biradiata	Bivalve	6	0.27	2.77	0.95	99.52	7
Culicidae sp.	Insect	1	0.04	0.34	0.16	99.68	8
Chronomid sp.	Insect	1	0.04	0.71	0.16	99.84	8
Pseudopolydora kempi	Polychaete	1	0.04	0.10	0.16	100.00	8

oligohaline estuaries, with a fringing salt marsh and limited connectivity to the ocean, but have rich and relatively abundant insect faunas (Tweedley *et al.* 2018, 2021). It was thus surprising not to find more insects in Hill Inlet, particularly during times of the year when salinities are lower thus favouring these species and the presence of fringing salt marsh vegetation which would provide habitat for adults.

The mean number of benthic macroinvertebrate species differed between regions ($F_{1, 8} = 11.25$, $P = 0.029$), being significantly greater in the lower (5.0±0.7 SE) than upper (2.0±0.5 SE) estuary. Despite the mean number of individuals being four times greater in the lower estuary (i.e. 101±61 SE vs 25±9 SE), it did not differ significantly between regions ($F_{1, 8} = 1.84$, $P = 0.243$). This was due to the large variability among the replicate samples from the lower estuary (range = 9–340). There was, however, a significant and moderate difference in benthic faunal composition between the two regions (ANOSIM $P = 0.008$; Global $R = 0.508$). This is clearly shown on the nMDS plot where there is a complete separation of points representing the samples from the lower (left hand side of the nMDS) and upper estuary (centre and right, Fig. 5). The microbivalve *Arthritica semen*, polychaete worm *C. capitata*,

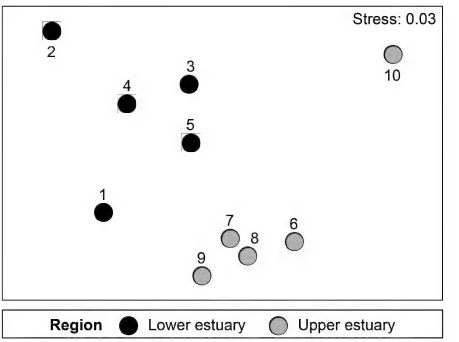

Figure 5. Two-dimensional nMDS ordination plot of the abundance of each benthic macroinvertebrate species from Ekman grab samples in each site in the deeper waters of Hill Inlet in June 2019.

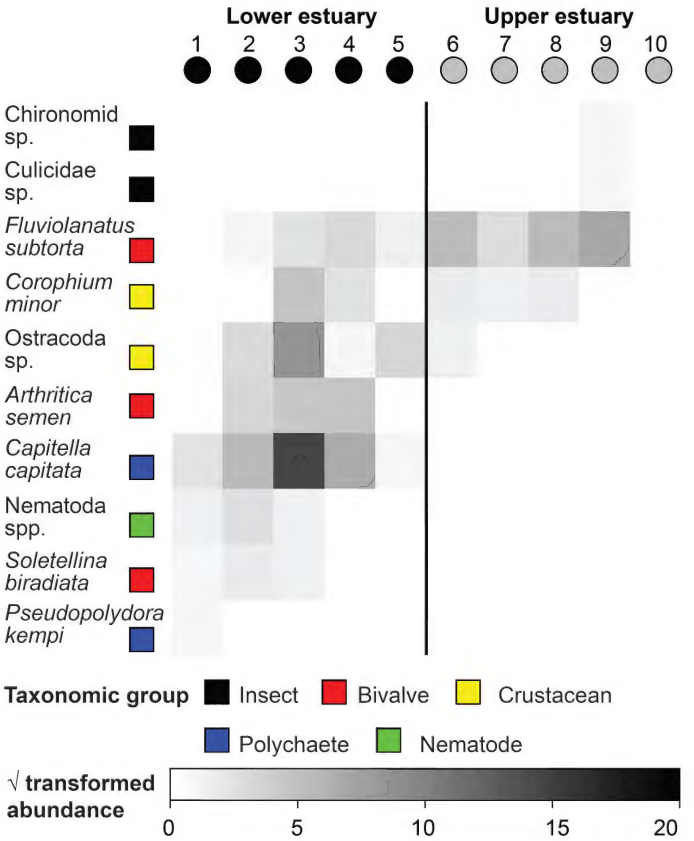

Figure 6. Shade plot of the square-root transformed abundance (225 cm^{-2}) of each benthic macroinvertebrate species from Ekman grab samples in the deeper waters of each site in Hill Inlet in June 2019. The broad taxonomic group for each species/taxa is colour coded.

the sunset shell *Soletellina biradiata* and Nematoda spp. typified the lower estuary and were not recorded at the upper sites (Fig. 6). The only taxa found in more than one of the sites in the upper estuary were the bivalve *F. subtorta* and the amphipod *Corophium minor,* although these species were also recorded at multiple sites in the lower estuary. The presence of these species throughout the entire estuary reflects their ability to tolerate a wide range of salinities (Morton 1982; Tweedley 2011). While it is hard to draw conclusions from the small range of samples collected here at one point in time, the relatively low diversity (cf. this study; Tweedley *et al.* 2021) could be due to the hypoxia present throughout much of the deeper waters (Fig. 2c). Hypoxia influences the diversity and composition of benthic fauna, reducing the number of species, particularly crustaceans (Tweedley *et al.* 2016b).

Summary

This study obtained the first quantitative data on the fish and invertebrate fauna of Hill Inlet a very small, seasonally-open estuary located in the northern most part of south-western Australia. Relatively few fish species were recorded, which likely reflects the high water levels present during sampling allowing fish to move into surrounding salt marsh and the bar at the mouth of the estuary being closed, preventing recruitment of marine species. Those species recorded are common in south-western Australian estuaries, with two able to complete their entire life cycle within Hill Inlet. The benthic fauna of the Hill Inlet was fairly depauperate and likely impacted by the presence of extensive bottom water hypoxia. As this study was conducted over a small temporal window, sampling should be repeated at a time of the year when water levels are lower and salinities are higher, either during summer or again in winter, but only after the bar has broken to provide a more holistic assessment of the fauna of Hill Inlet.

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Bird records for Yunderup, Murray River delta, Western Australia, 1967–2000

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Abstract

The Western Australian Naturalists' Club owns a field station, the Yunderup Naturalists Observatory, on Cooleenup Island in the Murray River delta. Habitats in the area include open woodland and shrubland, saline and freshwater swamps, ephemeral lakes, and extensive sand flats on the western side of the deltaic islands. Club members made detailed bird observations, conducted bird banding and contributed to the Australian Bird Count. These records are collated for 1967–2000, providing a comprehensive bird list for the area. The records are of 149 species, including 38 species of passerines and 111 species of non-passerines. They include both resident and migratory land and water birds. The most frequently recorded birds were Splendid Fairy-wren, Western Gerygone, Broad-tailed Thornbill, Grey Fantail, Eastern Great Egret and Little Pied Cormorant. Unusual birds include Red-tailed Tropicbird, Pacific Swift, Elegant Parrot and Rock Parrot. Banding records show Australian Pelican move from the Peel Inlet to the south coast of Western Australia. It is likely that population pressure on the area from the development of the city of Mandurah and the Shire of Murray, changes to the Peel Inlet following the opening of the Dawesville Channel in 1994 and warming and drying of the climate will impact the bird population of the area in the future.

Introduction

The Murray River delta in the south-west of Western Australia (WA) is between Pinjarra and Mandurah, in the Shire of Murray (Fig. 1). The nine deltaic islands are located where the Murray and Serpentine Rivers flow into the Peel Inlet. The islands are: Ballee (Bay Island), Cooleenup [Culenup, Culeenup] (Mill Island), Goongoolup, Jeegarnyeejip (Reserve Island), Jennala, Meeyip, Worallgarook, Yunderup (Long Island, Goat Island) and Little Yunderup. Their Aboriginal names were recorded by Surveyor A.J. Lewis in 1896 (Anon undated).

The Murray River Delta Reserve A20215 was gazetted as a National Park for the use and enjoyment of the public on 11 January 1935. It

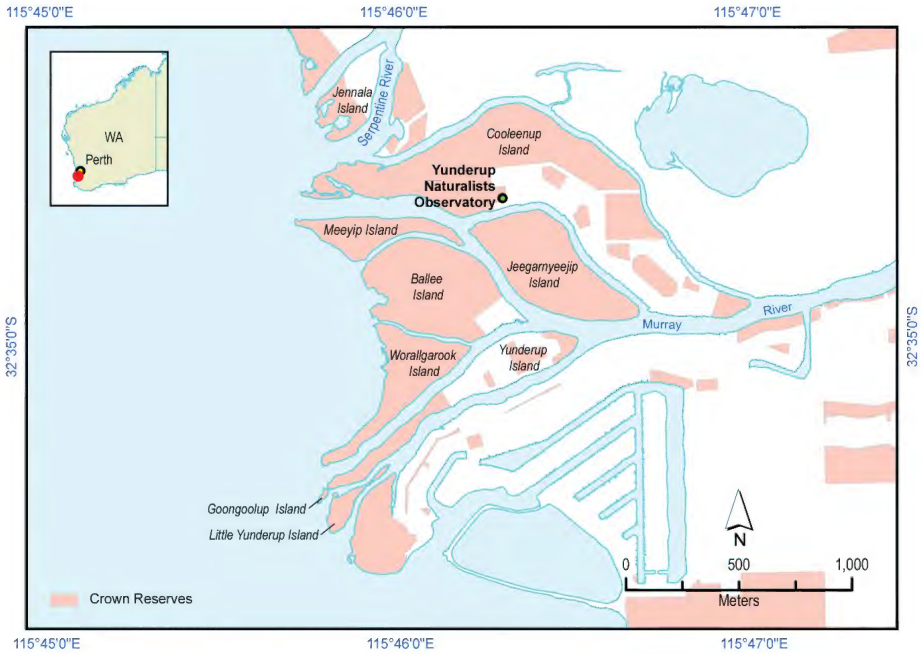

Figure 1. The deltaic islands at the mouth of the Murray and Serpentine rivers, showing the location of the Yunderup Naturalists Observatory on Cooleenup Island. Map courtesy of Department of Biodiversity Conservation and Attractions.

covers an area of 78.509 ha. There are also residential properties on parts of Ballee, Cooleenup and Yunderup Islands. Access to the islands is by boat.

These low-lying islands are fringed with *Casuarina obesa, Eucalyptus rudis* and *Melaleuca* spp. with central sandy ridges covered with *Jacksonia furcellata* and *Kunzea glabrescens* (Keighery *et al.* 2006). There are saline and freshwater swamps, ephemeral lakes, bushland, and extensive sand flats on the Inlet side of the islands (Serventy 1970).

Members of the Western Australian Naturalists' Club Inc. (the Club) made several excursions to these islands between 1967 and 1970. They were so impressed with the large number of water birds and waders in the shallows of the Peel Inlet, together with the area's potential for general natural history observations, that they decided to establish a field station. A formal request was made to the Lands and Surveys Department for a grant of land, and 'the Governor in Council approved that Lots 8 and 9 on Culeenup Island, being Reserve No. 5613, and totalling 1 acre in area, "should vest in and be held by the Western Australian Naturalists' Club in trust for the purpose of a Field Station" ' (Serventy 1970). The Yunderup Field Station, known as the Yunderup Naturalists Observatory (YNO) (32°34'39.7"S 115°46'18.2"E), was eventually opened in 1985 by the then Club President, Professor Bert Main (Erickson & Kingston 1984).

The original report by Serventy (1970) detailed the geomorphology and hydrology of the area and included a plant list, bird list, reptile records and notes on invertebrates. During the construction of the YNO, Club members stayed in alternative accommodation on Cooleenup Island, making observations as well as working on the new building. Once the YNO had been opened, it provided a focus for surveys of the flora and fauna of the region. A plant list was published by Hussey *et al.* (1992), which was updated and added to for all the deltaic islands by Keighery and Muir (2010). A list of vertebrates other than birds was published by Browne-Cooper *et al.* (1989). However, most of the observations were of birds, and these have not been published, although an unpublished species list was prepared by G. Elliott (2003).

Bird records made by Club members started in 1967, pre-dating the YNO. The records, which are mainly from Cooleenup Island, are in several forms: in loose-leaf binders, covering the period 1967–1985, in records submitted to the Australian Bird Count covering the period 1989–1995, and by bird banding records submitted to Australian Bird and Bat Banding Scheme (ABBBS) covering the period 1970–2002. Additional bird lists from 1984–2012 are recorded in diaries at YNO.

The aim of this paper is to collate the historical bird records collected by the Club from 1967–2000 and compare them with contemporary publications (Serventy & Whittell 1976; Storr & Johnstone 1988). These Yunderup records are important because they reflect a time when the area was relatively unmodified by development, with human-induced pressure on the environment being much greater today.

Methods

Bird names are from Western Australian Museum (2023). The bird records from Yunderup (mainly from Cooleenup Island) are in several forms. The first records are the Serventy 'stamp albums': loose leaf binders on non-passerines (Book 1) and passerines (Book 3), covering the period 1967–1985. The records in these Serventy 'stamp albums' were collated by G. Elliott (2003). They have now been digitised and are available from the Club (info@wanaturalists.org.au).

Additional bird lists were recorded in diaries at the YNO, the Red Book (1984–1994) and the Blue Book (1994–2012). These have also been digitised and are also available from the Club (info@wanaturalists.org.au). The information in these diaries is not always precise, for example an entry may state that xxx birds were observed without listing which ones. Additional species lists may have been prepared by Club members, but they have not been found.

There are additional records of birds in the general area of YNO which have been published in the Club's journal, the Western Australian Naturalist. These have been used to supplement the records from the Serventy 'stamp albums' and diaries.

Bird banding records covering the period 1970–2002 were obtained from ABBBS. They were submitted by B.G. Hutchison (1970–72), C.P.S. de Rebeira (1970–78), L. Broadhurst (1974–75), J.A.K. Lane (1976–80) and O. Mueller (1981–2002). Earlier data may be

available but have not been digitised (N. Perring, ABBBS, pers. comm.).

The Club also contributed records from the YNO to the Australian Bird Count in the period 1989–1995, with records submitted by O. Mueller. These records have been obtained from BirdLife Australia.

The records after 2000 are less comprehensive than those collected during the early days of the Club's observations at Yunderup. As a result, this collation ends in 2000, just before the last bird banding records were submitted by the Club. Bird bands and rings were returned to ABBBS in October 2001.

Results

Bird list

The birds recorded by the Club from Yunderup in the period 1967–2000, are presented in Tables 1 and 2. These records are by year, and the quality of the records is categorised by: 1: heard; 2: sighted; 3: banded; #breeding noted. Two additional records of non-passerines have been included. Both are from Coodanup, about 2 km northwest of the deltaic islands. These sightings are of Common Redshank which was recorded in 1985 (Jaensch & Blyth 1988), and Glossy Ibis, recorded in 1982. There are 38 species of passerines (Table 1) and 111 species of non-passerines (Table 2).

The intensity of recording is not known. However, the number of observing periods, which could be from one day to a long weekend, varied between years, from one in 1967, 1971, 1983 and 1984 to 26 in 1974. As there are several different habitats on the deltaic islands, not all habitats may have been visited every year. Also, not all bird lists mentioned in the YNO diaries have been found.

There is uncertainty as to the identity of some of the species, for example, Stubble Quail or Brown Quail were seen in 1979–1981, with uncertainty as to which species (Table 2), and the species of Corella is not known (Table 2). There is also uncertainty as to which species of White-tailed Black-Cockatoo (*Zanda* sp.) was seen: in the Serventy 'stamp albums' it is identified as *Calyptorhynchus* [=*Zanda*] *baudini*, however, it is most likely to be *Z. latirostris*, Carnaby's Cockatoo.

Passerines

The most frequently recorded passerines, recorded in at least 28 of the 34 years of observation were Splendid Fairy-wren, Brown Honeyeater, New Holland Honeyeater, Striated Pardalote, Western Gerygone, Broad-tailed Thornbill, White-backed Magpie, Rufous Whistler, Willie Wagtail, Grey Fantail, Australian Raven, Welcome Swallow and Grey-breasted White-eye (Table 1). The least frequently observed passerines, recorded less than five times in the 34 years of observation, were Western Little Wattlebird, Spotted Pardalote, Black-faced Woodswallow, Varied Sittella, Restless Flycatcher and Australian Reed Warbler.

Three species were not recorded after 1983; these are Western Spinebill, Dusky Woodswallow and Varied Sittella. The species only recorded since 1984 are Black-faced Woodswallow (in 1985) and Australian Reed Warbler (in 1991).

Breeding behaviour (nesting, feeding young or adults with young) was observed in some species in some years (Table 1, indicated with #).

Table 1. Passerines recorded from Yunderup 1967–2000. Key: 1: heard; 2: seen; 3: mist netting record:# nesting/breeding.

Common name	Latin name	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Family MALURIDAE																		
Splendid Fairy-wren	*Malurus splendens*		2	2	3	3	3	3	3	3	2	2	2	2	2	3	3	3
Family MELIPHAGIDAE																		
Western Spinebill	*Acanthorhynchus superciliosus*						2	2				1	3		2			
Brown Honeyeater	*Lichmera indistincta*	1	1	1	1	1	1	2	1	1	1	1	1	2	1	2	1	3
New Holland Honeyeater	*Phylidonyris novaehollandiae*			2	2		2	2	2	2	2	2	1	1	2	2	2	
White-fronted Chat	*Epthianura albifrons*				2		2	2	2		1				2	1		
Red Wattlebird	*Anthochaera carunculata*	1	1	1	1		1	2	2#	2	2	2#	2	2	2	2	2	
Western Little Wattlebird	*Anthochaera lunulata*							2										
Singing Honeyeater	*Gavicalis virescens*		1		2				2									
Family PARDALOTIDAE																		
Spotted Pardalote	*Pardalotus punctatus*												1	1				
Striated Pardalote	*Pardalotus striatus*	1	1	1	1	1	1	1	2#	1	2#	1	2	1	2	2	1	
Family ACANTHIZIDAE																		
Spotted Scrubwren	*Sericornis maculatus*			2	3	3	3	3	3	2	1			1	2	2	3	3
Weebill	*Smicrornis brevirostris*													2			2	
Western Gerygone	*Gerygone fusca*	1	1	1	1	1	1	1	2#	2#	2	2	2	2	2	2	2	2
Inland Thornbill	*Acanthiza apicalis*	1	2	2	3	3	3#	3	3	2#	2	2	2	2	2	3	3	3
Western Thornbill	*Acanthiza inornata*		1		2				2						1	2		
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*		2	2	3		2#	2#	2#	2	2	2	2	2	2#	3	2	3
Family ARTAMIDAE																		
Black-faced Woodswallow	*Artamus cinereus*																	
Dusky Woodswallow	*Artamus cyanopterus*		2	2			2	2							2			
Grey Butcherbird	*Cracticus torquatus*		1	2	2		1	1	2	1	2	1	2	2	2	2	1	1
White-backed Magpie	*Cracticus tibicen dorsalis*	1	2	2	2#	2	2#	2	2	2	2	2	2	2	2	2	2	1
Family CAMPEPHAGIDAE																		
Black-faced Cuckooshrike	*Coracina novaehollandiae*		2	2	2		2	2	2	2#	2	2	2	2	2	2	2	

Family NEOSITTIDAE																		
Varied Sittella	*Daphoenositta chrysoptera*			1								2			2			
Family PACHYCEPHALIDAE																		
Western Whistler	*Pachycephala fuliginosa occidentalis*		1	2	1	3	2	3	2	1	2	1	2	1		1		
Rufous Whistler	*Pachycephala rufiventris*	1	2	2	2	3	3	2	3#	2	2	2	2	2	2	2	2	
Grey Shrikethrush	*Colluricincla harmonica*		1	2	1		1	2	3	1	1	2	1	1	2	2	1	
Family RHIPIDURIDAE																		
Willie Wagtail	*Rhipidura leucophrys*	2	2	2	2	2	2#	2	2#	2#	2#	2	2	2	2	3	2	
Grey Fantail	*Rhipidura albiscapa*	1	2	2	3	3	2	2	2#	2	2	2	2	2#	2	3	2	3
Family MONARCHIDAE																		
Magpie-lark	*Grallina cyanoleuca*	2	2	2	2		1	2#	2	2	2	1	1	2	2#	2	2	
Restless Flycatcher	*Myiagra inquieta*				2													
Family CORVIDAE																		
Australian Raven	*Corvus coronoides*	1	1	1	2#	2	1	2	2	2	2	2	2	2	2	2	1	2
Family PETROICIDAE																		
Scarlet Robin	*Petroica boodang*		1	2	2	3	3	3	2#	2	2	2	2	2	2	2		
Family HIRUNDINIDAE																		
Welcome Swallow	*Hirundo neoxena*	2	2	2	2	2	2#	2	2	2#	2#	2	2	2	2	2	2	2
Tree Martin	*Petrochelidon nigricans*		2	2	2	2	2	2	2	2	2	2				2	2	
Family ACROCEPHALIDAE																		
Australian Reed Warbler	*Acrocephalus australis*																	
Family LOCUSTELLIDAE																		
Little Grassbird	*Poodytes gramineus*	1			2		2	1	2	2						2	2	
Family ZOSTEROPIDAE																		
Grey-breasted White-eye	*Zosterops lateralis*	1	1	1	2	1	2	2	2	2#	2	2	2	2	2	2	2	3
Family DICAEIDAE																		
Mistletoebird	*Dicaeum hirundinaceum*		1	2	1	2	2	1	2	1	1	1	1	1	1	1	1	
Family MOTACILLIDAE																		
Australian Pipit	*Anthus australis*				2		2		2		2	2						

Table 1. Passerines recorded from Yunderup 1967–2000. Key: 1: heard; 2: seen; 3: mist netting record:# nesting/breeding.

Common name	Latin name	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Family MALURIDAE																			
Splendid Fairy-wren	*Malurus splendens*	3	3	3	3#	3	3#	3	3	3	3	3	3	2#	3	3	2	3	33#
Family MELIPHAGIDAE																			
Western Spinebill	*Acanthorhynchus superciliosus*																		5
Brown Honeyeater	*Lichmera indistincta*	3	3	3	2	2	3	2		2	2	2		3#			3	3	30#
New Holland Honeyeater	*Phylidonyris novaehollandiae*	3	3	3	3	2	2	2	2	3	2	3	2		2	3	3	3	29
White-fronted Chat	*Epthianura albifrons*		2	2															9
Red Wattlebird	*Anthochaera carunculata*	3	3	3	2#	3	2#	2#	2#	2	2	2							26#
Western Little Wattlebird	*Anthochaera lunulata*				2														2
Singing Honeyeater	*Gavicalis virescens*		2	2	3	2		2	2		2								10
Family PARDALOTIDAE																			
Spotted Pardalote	*Pardalotus punctatus*				3														3
Striated Pardalote	*Pardalotus striatus*		3	2	2#	3#	2	2	2#	2	2	2	2				3		28#
Family ACANTHIZIDAE																			
Spotted Scrubwren	*Sericornis maculatus*	3	3	3	3#	3	3	3	3	3	3	3			3		3	3	27#
Weebill	*Smicrornis brevirostris*				2			2	2				2						6
Western Gerygone	*Gerygone fusca*	3	3	3	2	3	2	2	2	3	2	2	3		3	2	3		32#
Inland Thornbill	*Acanthiza apicalis*	3	3	3	3#	3	3	3	3	3	3	3	3	2			3	3	32#
Western Thornbill	*Acanthiza inornata*		2		2	2		2											9
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	3	3	3	3#	2		2									3		22
Family ARTAMIDAE																			
Black-faced Woodswallow	*Artamus cinereus*		2																1
Dusky Woodswallow	*Artamus cyanopterus*																		5
Grey Butcherbird	*Cracticus torquatus*		2	3	2	2	2	2	3#	3	2	2	2	1					27#
White-backed Magpie	*Cracticus tibicen dorsalis*		2	2	3#	2#	2	2	2	2	2	3	2	1	3				30#
Family CAMPEPHAGIDAE																			
Black-faced Cuckooshrike	*Coracina novaehollandiae*		2	2	2	2	2	2	2	2	2		2				2		25#

Family NEOSITTIDAE																			
Varied Sittella	*Daphoenositta chrysoptera*																		3
Family PACHYCEPHALIDAE																			
Western Whistler	*Pachycephala fuliginosa occidentalis*	3	3	2	3		3	2	2#	2	3	2	3		3	3			26#
Rufous Whistler	*Pachycephala rufiventris*	3	3	3	3	2	2	2	2	3	2	2	2		3	2			30#
Grey Shrikethrush	*Colluricincla harmonica*	3	3	2	3	2	3	2	2		2	2	2	2	1				27
Family RHIPIDURIDAE																			
Willie Wagtail	*Rhipidura leucophrys*	3	2	3#	2	3	2	2	2		2			2	2	2	2	2	30#
Grey Fantail	*Rhipidura albiscapa*	3	3	3	3#	3#	3	3	2	3	3	3	2	2	3	2	3	3	34#
Family MONARCHIDAE																			
Magpie-lark	*Grallina cyanoleuca*		2	2	2	2#	2	2	2#	2#	2#	2			2				26#
Restless Flycatcher	*Myiagra inquieta*					2													2
Family CORVIDAE																			
Australian Raven	*Corvus coronoides*		2	2	2#	2	2#	2	2	2	2	2		1			2		29#
Family PETROICIDAE																			
Scarlet Robin	*Petroica boodang*				2			2								1			17#
Family HIRUNDINIDAE																			
Welcome Swallow	*Hirundo neoxena*		2	2	2	2	2	2	2	2	2	2				2			28#
Tree Martin	*Petrochelidon nigricans*		2	2	2	2	2	2		2	2		2	2					22
Family ACROCEPHALIDAE																			
Australian Reed Warbler	*Acrocephalus australis*								2										1
Family LOCUSTELLIDAE																			
Little Grassbird	*Poodytes gramineus*		2	2	2#	2	2					2	2						15#
Family ZOSTEROPIDAE																			
Grey-breasted White-eye	*Zosterops lateralis*	3	3	3#	3#	3	3	3	2	3#	3	3	3		3	3	3	3#	33#
Family DICAEIDAE																			
Mistletoebird	*Dicaeum hirundinaceum*		2	2	3		2	2		2	2		3						23
Family MOTACILLIDAE																			
Australian Pipit	*Anthus australis*			2	2#	2			2	2									10#

Table 2. Non-passerines recorded from Yunderup 1967–2000. Key: *: naturalised exotic; 1: heard; 2: seen; 3: mist netting record:# nesting/ breeding.

Common name	Latin name	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Order ANSERIFORMES																		
Family ANATIDAE																		
Cape Barren Goose	*Cereopsis novaehollandiae*																	
Black Swan	*Cygnus atratus*			2			2	2	2	2	2	2	2	2	2		2	
Australian Shelduck	*Tadorna tadornoides*			2	2		2	2	2	2	2	2	2	2	2	2	2	
Pink-eared Duck	*Malacorhynchus membranaceus*																	
Australian Wood Duck	*Chenonetta jubata*																	
Pacific Black Duck	*Anas superciliosa*		2	2	2	2	2#	2	2#	2#	2	2	2	2	2	2	2	2
Australasian Shoveler	*Spatula rhynchotis*							2									2	
Grey Teal	*Anas gracilis*		2	2		2	2#	2	2	2	2	2	2	2	2	2	2	
Chestnut Teal	*Anas castanea*											2						
Hardhead	*Aythya australis*														2			
Musk Duck	*Biziura lobata*		2						2				2		2	2		
Order GALLIFORMES																		
Family PHASIANIDAE																		
Stubble Quail or Brown Quail	*Coturnix pectoralis* or *Synoicus ypsilophorus*													2	2	2		
Order PODICIPEDIFORMES																		
Family PODICIPEDIDAE																		
Great Crested Grebe	*Podiceps cristatus*								2			2		2				
Hoary-headed Grebe	*Poliocephalus poliocephalus*										2	2				2		
Order PHAETHONTIFORMES																		
Family PHAETHONTIDAE																		
Red-tailed Tropicbird	*Phaethon rubricauda*																	
Order PELECANIFORMES																		
Family THRESKIORNITHIDAE																		
Australian White Ibis	*Threskiornis molucca*									2				2		2		
Straw-necked Ibis	*Threskiornis spinicollis*		2		2		2	2	2	2	2	2	2					
Glossy Ibis (at Coodanup)	*Plegadis falcinellus*																2	
Yellow-billed Spoonbill	*Platalea flavipes*										2							

Family ARDEIDAE																		
Australasian Bittern	*Botaurus poiciloptilus*																	
Nankeen Night Heron	*Nycticorax caledonicus*		2		2		2	2	2	2#	2#	2#	2	2	2	2	2	2
White-necked Heron	*Ardea pacifica*									2	2							
Great Egret	*Ardea modesta*	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Little Egret	*Egretta garzetta*																2	
White-faced Heron	*Egretta novaehollandiae*		2	2	2#	2	2	2	2	2	2	2	2	2	2	2	2	2
Eastern Reef Heron	*Egretta sacra*										2	2				2		
Family PELECANIDAE																		
Australian Pelican	*Pelecanus conspicillatus*		2	2	2	2	2	2	2#	2	3	3	3	3	3	2	2	2
Family PHALACROCORACIDAE																		
Little Pied Cormorant	*Microcarbo melanoleucos*	2	2	2	2	2	2	2	2	2	2	2	2	2	2#	2	2	2
Little Black Cormorant	*Phalacrocorax sulcirostris*		2	2	2	2	2	2	2	2	2	2	2	2	2#	2	2	2
Pied Cormorant	*Phalacrocorax varius*		2	2	2	2	2	2	2	2	2	2	2	2	2	2		
Great Cormorant	*Phalacrocorax carbo*		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Family ANHINGIDAE																		
Australasian Darter	*Anhinga novaehollandiae*	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Order ACCIPITRIFORMES																		
Family PANDIONIDAE																		
Osprey	*Pandion haliaetus*			2			2		2	2		2			2	2		
Family ACCIPITRIDAE																		
Black-shouldered Kite	*Elanus axillaris*						2	2			2				2	2		
Little Eagle	*Hieraaetus morphnoides*							2	2		2	2	2	2	2	2	2	
Wedge-tailed Eagle	*Aquila audax*																	
Brown Goshawk	*Accipiter fasciatus*				2				2	2					2			
Collared Sparrowhawk	*Accipiter cirrocephalus*									2								
Swamp Harrier	*Circus approximans*																	
Whistling Kite	*Haliastur sphenurus*			2	2		2	2	2	2	2	2	2	2	2	1	2	2
White-bellied Sea-Eagle	*Haliaeetus leucogaster*						2				2				2		2	
Order GRUIFORMES																		
Family RALLIDAE																		
Buff-banded Rail	*Hypotaenidia philippensis*																	
Australian Spotted Crake	*Porzana fluminea*						2									2		
Spotless Crake	*Zapornia tabuensis*																	
Australasian Swamphen	*Porphyrio melanotus*		2	2	2				2#	2#								
Dusky Moorhen	*Gallinula tenebrosa*		2	2	2	2	2	2	2	2#	2#	2						
Black-tailed Native-hen	*Tribonyx ventralis*									2								
Eurasian Coot	*Fulica atra*			2	2	2		2	2	2	2	2			2	2	2	

Table 2. (cont.)

Common name	Latin name	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Order CHARADRIIFORMES																		
Family TURNICIDAE																		
Painted Buttonquail	*Turnix varius*																	
Family HAEMATOPODIDAE																		
Pied Oystercatcher	*Haematopus longirostris*																	
Family RECURVIROSTRIDAE																		
Black-winged Stilt	*Himantopus himantopus*			2				2	2	2	2	2	2	2	2	2	2	
Pied Stilt	*Himantopus himantopus leucocephalus*					2								2	2		2	
Red-necked Avocet	*Recurvirostra novaehollandiae*			2	2	2	2		2	2	2	2		2	2	2	2	
Family CHARADRIIDAE																		
Grey Plover	*Pluvialis squatarola*				2	2		2	2	2	2	2	2		2	2	2	
Red-capped Plover	*Charadrius ruficapillus*			2	2	2	2	2	2	2		2		2	2		2	
Lesser Sand Plover	*Charadrius mongolus*								2									
Greater Sand Plover	*Charadrius leschenaultii*				2	2			2								2	
Hooded Plover	*Thinornis cucullatus*																	
Black-fronted Dotterel	*Elseyornis melanops*								2									
Family SCOLOPACIDAE																		
Black-tailed Godwit (WA Nts 2(4) 1950: 90-91)	*Limosa limosa*								2	2								
Bar-tailed Godwit	*Limosa lapponica*								2									
Common Redshank (near Coodanup)	*Tringa totanus*																	
Marsh Sandpiper	*Tringa stagnatilis*																	
Common Greenshank	*Tringa nebularia*		1	1	1	2	2	2	2	2	2	2	1	2	2	2		
Wood Sandpiper	*Tringa glareola*								2									
Grey-tailed Tattler	*Tringa brevipes*																	
Terek Sandpiper	*Xenus cinerea*																	
Common Sandpiper	*Actitis hypoleucos*		2		2	2	2	2	2	2	2	2	2	2	2	2	2	
Ruddy Turnstone	*Arenaria interpres*																	
Great Knot	*Calidris tenuirostris*																2	
Red Knot	*Calidris canutus*								2	2	2							
Red-necked Stint	*Calidris ruficollis*	2		2	2	2	2	2	2	2	2	2		2	2	2	2	

Long-toed Stint	*Calidris subminuta*																							2	
Pectoral Sandpiper	*Calidris melanotos*									2														2	
Sharp-tailed Sandpiper	*Calidris acuminata*					2			2	2				2					2	2				2	
Curlew Sandpiper	*Calidris ferruginea*				2	2			2	2			2	2										2	
Ruff	*Calidris pugnax*																							2	
Family LARIDAE																									
Silver Gull	*Chroicocephalus novaehollandiae*	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Asian Gull-billed Tern	*Gelochelidon nilotica*																								
Caspian Tern	*Hydroprogne caspia*		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Greater Crested Tern	*Thalasseus bergii*		2	2	2		2	2	2	2	2	2	2	2	2	2			2	2	2				
Fairy Tern	*Sternula nereis*			2				2	2	2														2	
Whiskered Tern	*Chlidonias hybrida*			2	2					2	2	2						2						2	
Order COLUMBIFORMES																									
Family COLUMBIDAE												1										2			
Spotted Turtle-Dove	**Spilopelia chinensis*								2	2	2	2	1	2	2	2				2		2		2	
Laughing Turtle-Dove	**Spilopelia senegalensis*								2	2	2	2	2								2	2		2	
Common Bronzewing	*Phaps chalcoptera*				2	2			2	2	2	2	2								2	2		2	
Brush Bronzewing	*Phaps elegans*																				2				
Order CUCULIFORMES																									
Family CUCULIDAE																									
Horsfield's Bronze Cuckoo	*Chalcites basalis*				2			1	2	3				2											
Shining Bronze Cuckoo	*Chalcites lucidus*	1	1	3			2#	2#	2	2	2	2	1	1	2	1									
Pallid Cuckoo	*Heteroscenes pallidus*			1			1	1	2	1	2	1		1	1	1									
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	1	1	1			3	2	1	2	1	1	1	1	2	1									
Order STRIGIFORMES																									
Family TYTONIDAE																									
Boobook Owl	*Ninox boobook*									2					1	2									
Order CAPRIMULGIFORMES																									
Family PODARGIDAE																									
Tawny Frogmouth	*Podargus strigoides*				3#		2#	3	1	2														2#	
Order APODIFORMES																									
Family APODIDAE																									
Pacific Swift	*Apus pacificus*													2											

Table 2. (cont.)

Common name	Latin name	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Order CORACIIFORMES																		
Family ALCEDINIDAE																		
Laughing Kookaburra	**Dacelo novaeguineae*			1	1	2	2	2	2	2	2	2	1	2	2	2	1	
Sacred Kingfisher	*Todiramphus sanctus*	1	2	1	2	3	2	2	2	2	2	2	2	2	2	3	2	1
Family MEROPIDAE																		
Rainbow Bee-eater	*Merops ornatus*		1	1	1	3	2	2	2	2	2	2	2		2	2	2	
Order FALCONIFORMES																		
Family FALCONIDAE																		
Australian Kestrel	*Falco cenchroides*						2		2	2		2			2	2		
Australian Hobby	*Falco longipennis*								2									
Brown Falcon	*Falco berigora*																	
Peregrine Falcon	*Falco peregrinus*									2							2	
Order PSITTACIFORMES																		
Family CACATUIDAE																		
White-tailed Black-Cockatoo	*Zanda* sp.		1		2		2	1	2	2	1	2	2	1	2			
Galah	*Eolophus roseicapilla*																	
Corella	*Cacatua* sp.									2								
Family PSITTACULIDAE																		
Purple-crowned Lorikeet	*Parvipsitta porphyrocephala*		2						2	2			2	1				
Red-capped Parrot	*Purpureicephalus spurius*		2	2	2#		2	2	2	2	2	2	1	2	2	2	2	
Twenty-eight Parrot	*Barnardius zonarius semitorquatus*		2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1
Western Rosella	*Platycercus icterotis*								2				2		2			
Elegant Parrot	*Neophema elegans*																	
Rock Parrot	*Neophema petrophila*							2										
Regent Parrot	*Polytelis anthopeplus*							2	2	2				2	2		2	

Table 2. Non-passerines recorded from Yunderup 1967–2000. Key: *: naturalised exotic; 1: heard; 2: seen; 3: mist netting record:# nesting/ breeding.

Common name	Latin name	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Order ANSERIFORMES																			
Family ANATIDAE																			
Cape Barren Goose	*Cereopsis novaehollandiae*					2		2											2
Black Swan	*Cygnus atratus*		2	2	2#	2	2	2	2		2	2							20#
Australian Shelduck	*Tadorna tadornoides*		2	2#	2	2	2	2#	2	2	2	2	2	2	2	2	2	2#	29#
Pink-eared Duck	*Malacorhynchus membranaceus*												2						1
Australian Wood Duck	*Chenonetta jubata*				2	2		2		2#	2#		2#					2	7#
Pacific Black Duck	*Anas superciliosa*		2	2#	2#	2	2#	2	2	2#	2#		2#	2	2	2#	2#	2	31#
Australasian Shoveler	*Spatula rhynchotis*																2		3
Grey Teal	*Anas gracilis*		2	2#	2#	2	2#	2	2	2#	2			2			2		25#
Chestnut Teal	*Anas castanea*																		1
Hardhead	*Aythya australis*																		1
Musk Duck	*Biziura lobata*		2#		2														7#
Order GALLIFORMES																			
Family PHASIANIDAE																			
Stubble Quail or Brown Quail	*Coturnix pectoralis* or *Synoicus ypsilophorus*																		3
Order PODICIPEDIFORMES																			
Family PODICIPEDIDAE																			
Great Crested Grebe	*Podiceps cristatus*			2															4
Hoary-headed Grebe	*Poliocephalus poliocephalus*			2	2	2	2		2		2			2					10
Order PHAETHONTIFORMES																			
Family PHAETHONTIDAE																			
Red-tailed Tropicbird	*Phaethon rubricauda*						2												1
Order PELECANIFORMES																			
Family THRESKIORNITHIDAE																			
Australian White Ibis	*Threskiornis molucca*		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	19
Straw-necked Ibis	*Threskiornis spinicollis*																		9
Glossy Ibis (at Coodanup)	*Plegadis falcinellus*																		1
Yellow-billed Spoonbill	*Platalea flavipes*		2	2	2	2	2	2#	2	2	2	2	2		2	2		2	15#

Table 2. (cont.).

Common name	Latin name	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Family ARDEIDAE																			
Australasian Bittern	*Botaurus poiciloptilus*								2										1
Nankeen Night Heron	*Nycticorax caledonicus*		2	2#	2	2	2	2	2	2					2		2	2	25#
White-necked Heron	*Ardea pacifica*			2	2			2											5
Great Egret	*Ardea modesta*		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	33
Little Egret	*Egretta garzetta*		2	2	2	2	2	2		2	2		2					2	11
White-faced Heron	*Egretta novaehollandiae*	3	2	2#	2#	2#	2	2	2#	2	2	2			2#		2	2	30#
Eastern Reef Heron	*Egretta sacra*																		3
Family PELECANIDAE																			
Australian Pelican	*Pelecanus conspicillatus*		2	2	2	2	2	2#	2	2	2	2	2			2	2#	2	30#
Family PHALACROCORACIDAE																			
Little Pied Cormorant	*Microcarbo melanoleucos*	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	33#
Little Black Cormorant	*Phalacrocorax sulcirostris*		2	2	2	2	2	2	2	2	2					2	2#		27#
Pied Cormorant	*Phalacrocorax varius*		2		2	2	2	2	2	2							2		22
Great Cormorant	*Phalacrocorax carbo*		2	2	2	2	2	2	2	2	2								24
Family ANHINGIDAE																			
Australasian Darter	*Anhinga novaehollandiae*		2	2	2	2#	2	2#	2#		2		2			2#	2#	2#	29#
Order ACCIPITRIFORMES																			
Family PANDIONIDAE																			
Osprey	*Pandion haliaetus*		2	2	2	2	2	2	2		2	2	2	2	2	2			20
Family ACCIPITRIDAE																			
Black-shouldered Kite	*Elanus axillaris*			2	2		2		2	2									10
Little Eagle	*Hieraaetus morphnoides*				2		2	2			2		2						14
Wedge-tailed Eagle	*Aquila audax*											2							1
Brown Goshawk	*Accipiter fasciatus*		2								2								6
Collared Sparrowhawk	*Accipiter cirrocephalus*			2	2														3
Swamp Harrier	*Circus approximans*			2	2	2	2	2				2					2		7
Whistling Kite	*Haliastur sphenurus*		2	2	2	2	2	2	2	2	2	2	2		2			2	27
White-bellied Sea-Eagle	*Haliaeetus leucogaster*			2	2			2	2						2				9

Order GRUIFORMES																		
Family RALLIDAE																		
Buff-banded Rail	*Hypotaenidia philippensis*		2	2	2	2	2				2						2	7
Australian Spotted Crake	*Porzana fluminea*										2							3
Spotless Crake	*Zapornia tabuensis*			2		2	2	2	1	2	2	1		1			1	10
Australasian Swamphen	*Porphyrio melanotus*					2												6#
Dusky Moorhen	*Gallinula tenebrosa*		2	2#	2	2	2	2	2	2	2#		2#	2	2		2	23#
Black-tailed Native-hen	*Tribonyx ventralis*		2															2
Eurasian Coot	*Fulica atra*			2	2	2	2	2		2	2							18
Order CHARADRIIFORMES																		
Family TURNICIDAE																		
Painted Buttonquail	*Turnix varius*			2														1
Family HAEMATOPODIDAE																		
Pied Oystercatcher	*Haematopus longirostris*		2	2	2	2		2	2	2	2		2#			2		10#
Family RECURVIROSTRIDAE																		
Black-winged Stilt	*Himantopus himantopus*	2	2	2	2	2	2	2	2		2	2	2					22
Pied Stilt	*Himantopus himantopus leucocephalus*			2	2	2						2						8
Red-necked Avocet	*Recurvirostra novaehollandiae*	2	2	2	2	2	2	2	2		2	2	2					23
Family CHARADRIIDAE																		
Grey Plover	*Pluvialis squatarola*		2	2	2	2	2	2	2	2		2	2				2	22
Red-capped Plover	*Charadrius ruficapillus*		2	2#	2	2	2	2#	2	2#	2#							20#
Lesser Sand Plover	*Charadrius mongolus*		2															2
Greater Sand Plover	*Charadrius leschenaultii*																2	5
Hooded Plover	*Thinornis cucullatus*			2#		2												2#
Black-fronted Dotterel	*Elseyornis melanops*				2#	2						2						4#
Family SCOLOPACIDAE																		
Black-tailed Godwit (WA Nts 2(4) 1950: 90-91)	*Limosa limosa*				2								2					4
Bar-tailed Godwit	*Limosa lapponica*			2	2	2	2	2	2	2	2		2				2	11
Common Redshank (near Coodanup)	*Tringa totanus*		2															1
Marsh Sandpiper	*Tringa stagnatilis*			2	2	2												3
Common Greenshank	*Tringa nebularia*		2	2	2	2	2	2	2	2	2	2						24
Wood Sandpiper	*Tringa glareola*																	1
Grey-tailed Tattler	*Tringa brevipes*		2					2	2					2				4
Terek Sandpiper	*Xenus cinerea*				2	2	2											3

Table 2. (cont.).

Common name	Latin name	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Common Sandpiper	*Actitis hypoleucos*		2	2	2	2	2	2	2	2		2	2		2			2	26
Ruddy Turnstone	*Arenaria interpres*					2	2										2		3
Great Knot	*Calidris tenuirostris*					2		2	2										4
Red Knot	*Calidris canutus*		2	2				2	2										7
Red-necked Stint	*Calidris ruficollis*		2	2		2	2	2	2	2			2						22
Long-toed Stint	*Calidris subminuta*																		1
Pectoral Sandpiper	*Calidris melanotos*																		2
Sharp-tailed Sandpiper	*Calidris acuminata*	2	2	2		2		2	2										13
Curlew Sandpiper	*Calidris ferruginea*	2	2	2		2	2	2	2	2									15
Ruff	*Calidris pugnax*																		1
Family LARIDAE																			
Silver Gull	*Chroicocephalus novaehollandiae*		2	2	2	2	2	2	2		2	2					2#		27#
Asian Gull-billed Tern	*Gelochelidon nilotica*			2				2											2
Caspian Tern	*Hydroprogne caspia*		2	2	2	2	2	2#	2	2	2	2							25#
Greater Crested Tern	*Thalasseus bergii*		2	2	2	2	2	2	2	2									20
Fairy Tern	*Sternula nereis*			2		2		2	2	2									10
Whiskered Tern	*Chlidonias hybrida*			2							2								9
Order COLUMBIFORMES																			
Family COLUMBIDAE																			
Spotted Turtle-Dove	**Spilopelia chinensis*				2		2	1				2		1					7
Laughing Turtle-Dove	**Spilopelia senegalensis*		2	2		2	2	2											15
Common Bronzewing	*Phaps chalcoptera*		2	2	2	2	2	2	2	2	2	2	2#	2				2	23#
Brush Bronzewing	*Phaps elegans*										2				2		2		4
Order CUCULIFORMES																			
Family CUCULIDAE																			
Horsfield's Bronze Cuckoo	*Chalcites basalis*		3	1		3	2#					3			3			3	12#
Shining Bronze Cuckoo	*Chalcites lucidus*	3	3	3	2		3	2										2	20#
Pallid Cuckoo	*Heteroscenes pallidus*		2		1														13
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	3	2	2	2	3	2	1		1		1							23
Order STRIGIFORMES																			
Family TYTONIDAE																			
Boobook Owl	*Ninox boobook*					1	2												5

Order CAPRIMULGIFORMES																	
Family PODARGIDAE																	
Tawny Frogmouth	*Podargus strigoides*	3	2	2	2			2	2#							2	13#
Order APODIFORMES																	
Family APODIDAE																	
Pacific Swift	*Apus pacificus*																1
Order CORACIIFORMES																	
Family ALCEDINIDAE																	
Laughing Kookaburra	**Dacelo novaeguineae*			2		2	2	3	2	2	2	2					22
Sacred Kingfisher	*Todiramphus sanctus*	3	3	3	3	2	2	2	2	3	2			2#		2	29#
Family MEROPIDAE																	
Rainbow Bee-eater	*Merops ornatus*				2		2										16
Order FALCONIFORMES																	
Family FALCONIDAE																	
Australian Kestrel	*Falco cenchroides*		2		2	2	2		2	2							12
Australian Hobby	*Falco longipennis*									2		2					3
Brown Falcon	*Falco berigora*										2						1
Peregrine Falcon	*Falco peregrinus*			2							2						4
Order PSITTACIFORMES																	
Family CACATUIDAE																	
White-tailed Black-Cockatoo	*Zanda* sp.		2	2	2	2		2	2	2	2		2				20
Galah	*Eolophus roseicapilla*							2	2								2
Corella	*Cacatua* sp.																1
Family PSITTACULIDAE																	
Purple-crowned Lorikeet	*Parvipsitta porphyrocephala*																5
Red-capped Parrot	*Purpureicephalus spurius*		2	2	2	2	2	2#	2	2#	2	2	2	2	2	2	28#
Twenty-eight Parrot	*Barnardius zonarius semitorquatus*		2	2	2		2		2	2	2	2	2				25
Western Rosella	*Platycercus icterotis*				2												4
Elegant Parrot	*Neophema elegans*										2						1
Rock Parrot	*Neophema petrophila*																1
Regent Parrot	*Polytelis anthopeplus*	1		2	2	2		2				2					12

These are Splendid Fairy-wren, Brown Honeyeater, Red Wattlebird, Striated Pardalote, Spotted Scrubwren, Western Gerygone, Broad-tailed Thornbill, Yellow-rumped Thornbill, Grey Butcherbird, White-backed Magpie, Black-faced Cuckooshrike, Western Whistler, Rufous Whistler, Willie Wagtail, Grey Fantail, Magpie-lark, Australian Raven, Scarlet Robin, Welcome Swallow, Little Grassbird, Grey-breasted White-eye and Australian Pipit.

Non-passerines

The most frequently recorded non-passerines, recorded in at least 28 of the 34 years of observations were Australian Shelduck, Pacific Black Duck, Eastern Great Egret, White-faced Heron, Australian Pelican, Little Pied Cormorant, Australasian Darter, Sacred Kingfisher and Red-capped Parrot (Table 2). The least frequently recorded non-passerines, recorded less than five times in the 34 years of observation, were Cape Barren Goose, Pink-eared Duck, Chestnut Teal, Hardhead, Stubble or Brown Quail, Great Crested Grebe, Red-tailed Tropicbird, Glossy Ibis, Australasian Bittern, Eastern Reef Heron, Wedge-tailed Eagle, Collared Sparrowhawk, Australian Spotted Crake, Black-tailed Native-hen, Painted Button-quail, Lesser Sand Plover, Hooded Plover, Black-fronted Dotterel, Black-tailed Godwit, Common Redshank, Marsh Sandpiper, Wood Sandpiper, Grey-tailed Tattler, Terek Sandpiper, Ruddy Turnstone, Great Knot, Long-toed Stint, Pectoral Sandpiper, Ruff, Gull-billed Tern, Brush Bronzewing, Pacific Swift, Australian Hobby, Brown Falcon, Peregrine Falcon, Galah, Corella, Western Rosella, Elegant Parrot and Rock Parrot.

Thirteen species of non-passerines were not recorded after 1983; these were Chestnut Teal, Hardhead, Stubble or Brown Quail, Glossy Ibis, Eastern Reef Heron, Wood Sandpiper, Long-toed Stint, Pectoral Sandpiper, Ruff, Pacific Swift, Corella sp., Purple-crowned Lorikeet and Rock Parrot (Table 2). The species only recorded since 1984 are Cape Barren Goose, Pink-eared Duck, Australian Wood Duck, Red-tailed Tropicbird, Australasian Bittern, Wedge-tailed Eagle, Swamp Harrier, Buff-banded Rail, Spotless Crake, Painted Button-quail, Pied Oystercatcher, Hooded Plover, Common Redshank, Marsh Sandpiper, Grey-tailed Tattler, Terek Sandpiper, Ruddy Turnstone, Gull-billed Tern, Brown Falcon, Galah and Elegant Parrot.

Breeding behaviour (nesting, feeding young, or adults with young) was observed in some species in some years (Table 2, indicated by #). These are Black Swan, Australian Shelduck, Australian Wood Duck, Pacific Black Duck, Grey Teal, Australasian Shoveler, Musk Duck, Yellow-billed Spoonbill, Nankeen Night Heron, White-faced Heron, Australian Pelican, Little Pied Cormorant, Little Black Cormorant, Australasian Darter, Purple Swamphen, Dusky Moorhen, Pied Oystercatcher, Red-capped Plover, Hooded Plover, Black-fronted Dotterel, Silver Gull, Caspian Tern, Common Bronzewing, Horsfield's Bronze Cuckoo, Shining Bronze Cuckoo, Tawny Frogmouth, Sacred Kingfisher and Red-capped Parrot.

Bird banding records

Banding records from Cooleenup have been provided by ABBBS. These show that 1282 birds were banded between

1970–2000. The species banded are indicated as 3 in Tables 1 and 2.

There were 24 species of passerines banded: Splendid Fairy-wren (248), Western Spinebill (1), Brown Honeyeater (25), New Holland Honeyeater (30), Red Wattlebird (12), Singing Honeyeater (1), Spotted Pardalote (2), Striated Pardalote (six), Spotted Scrubwren (128), Western Gerygone (14), Broad-tailed Thornbill (89), Western Thornbill (13), Yellow-rumped Thornbill (13), Grey Butcherbird (6), Australian Magpie (3), Western Whistler (19), Rufous Whistler (18), Grey Shrike-thrush (6), Willie Wagtail (4), Grey Fantail (55), Scarlet Robin (5), Grey-breasted White-eye (354) and Mistletoebird (2).

There were nine species of non-passerines banded: White-faced Heron (1), Australian Pelican (190), Horsfield's Bronze-Cuckoo (6), Shining Bronze-Cuckoo (6), Fan-tailed Cuckoo (4), Tawny Frogmouth (4), Laughing Kookaburra (2), Sacred Kingfisher (14) and Rainbow Bee-eater (1).

Recoveries of banded birds provide data on longevity and distance travelled. Recovery data from ABBBS shows 365 banded birds were recovered. All recoveries other than Australian Pelican were at Cooleenup. The longevity of the oldest recaptures of birds other than Australian Pelican is shown in Table 3. This shows that Spotted Scrubwren can live for at least 12 years and 3 months, Tawny Frogmouth can live for at least 6 years and 5 months, Grey-breasted White-eye can live for at least 5 years and 11 months and Splendid Fairy-wren for at least 5 years and 5 months.

Table 3. Maximum number of months elapsed from banding to recapture for bush birds on Cooleenup Island.

Band	Common name	Date Banded	Age	Date Recovered	Elapsed Months
01324631	Splendid Fairy-wren	3.10.1981	1	16.3.1987	65
02374646	Brown Honeyeater	12.9.1996	1	13.9.1996	0
03310958	New Holland Honeyeater	27.9.1994	1	11.10.1999	60
07037348	Red Wattlebird	30.3.1986	1	26.9.1987	17
02159073	Spotted Scrubwren	23.11.1986	1	19.3.1999	147
01545431	Western Gerygone	28.5.1988	1	15.10.1989	16
01545421	Broad-tailed Thornbill	27.3.1988	1	21.3.1992	47
01448781	Yellow-rumped Thornbill	25.8.1984	1	12.5.1985	8
06008747	Grey Butcherbird	1.11.1986	1	19.11.1989	36
03310955	Western Whistler	28.12.1993	1	29.12.1994	12
05008949	Grey Shrike-thrush	30.6.1984	1	27.4.1987	34
03112475	Willie Wagtail	16.9.1984	1	27.1.1986	16
01448758	Grey Fantail	4.5.1984	1	2.9.1984	4
01458812	Grey-breasted White-eye	1.11.1986	1	10.10.1992	71
03112105	Shining Bronze-Cuckoo	28.11.1970	Juvenile	28.11.1970	0
10015857	Tawny Frogmouth	12.1.1984	1	26.8.1990	79
05008947	Sacred Kingfisher	3.1.1984	1	19.12.1986	47

The Australian Pelican data are treated as a sub-set because these birds are more mobile. Between November 1976 and March 1980, 190 Australian Pelican were banded at the mouth of the Serpentine River by J.A.K. Lane. Fifteen banded birds were recovered (Table 4). Recoveries were both close to where the birds had been banded (e.g. Yunderup Canals, Peel Inlet), but also along the south coast of WA (Hardy Inlet, Wilson Inlet, Princess Royal Harbour), a distance of more than 300 km. The greatest time between banding and recapture was 17 years 7 months.

Australian Bird Count records

There were 262 observations which were made in 20 months, between November 1989 and July 1995. In complete years, observations were made on either three or four months in the year, but not necessarily in the same months each year.

Thirty-five species were seen (Table 5). The most frequently seen was Grey Fantail (20 occasions), followed by Splendid Fairy-wren (17 occasions). The largest flock size was White-tailed Black-Cockatoo (24 birds), followed by Tree Martin (16 birds).

Discussion

The bird lists presented here amply support the original intention of the Club to make natural history observations from a base on Cooleenup Island (Serventy 1970). The 149 species listed (Tables 1 and 2) are from several different habitats, which are suitable for land and water birds, both resident

Table 4. Recoveries of Australian Pelicans banded at the mouth of the Serpentine River 1976–1980.

Band	Date banded	Recovery locality	Date recovered	Distance travelled (km)	Elapsed time (months)
17001628	17 Nov 1976	Princess Royal Harbour, WA	05 Nov 1977	336	11
17001897	10 Mar 1977	South Yunderup Canals, WA	30 Jun 1992	2	183
17001888	10 Mar 1977	Yunderup Canals, WA	19 Jan 1981	2	46
17001921	23 Mar 1977	Hardy Inlet, Augusta, WA	18 Jan 1978	197	9
17001935	24 Apr 1977	The Chimneys, Peel Inlet, WA	01 Nov 1978	7	18
17001934	27 Apr 1977	Lake Monger, WA	23 Nov 1977	69	6
17001975	07 Jul 1977	Princess Royal Harbour, WA	29 Nov 1978	336	16
17001989	29 Jul 1977	Leschenault Inlet, WA	11 Apr 1979	78	20
17001978	29 Jul 1977	Olive Rd, Falcon, Harvey Estuary, Mandurah, WA	00 Nov 1988	15	135
17001993	29 Jul 1977	Peel Inlet, Mandurah, WA	19 Apr 1987	5	116
17001992	29 Jul 1977	Wilson Inlet, WA	10 Oct 1977	308	2
17002074	01 Sep 1977	Muchea, WA	16 Aug 1980	113	35
17002074	01 Sep 1977	Wilson Inlet, WA	16 Jan 1978	308	4
17002138	02 Sep 1977	Pelican Point, Swan River, WA	19 Dec 1977	67	3
17002835	27 Mar 1980	Creery Island, Mandurah Estuary, WA	02 Nov 1997	4	211

Table 5. Australian Bird Count records, recorded on 20 occasions between November 1989 and July 1995.

Passerine			Non-passerine		
Name	**Occasions seen**	**Flock size**	**Name**	**Occasions seen**	**Flock size**
Splendid Fairy-wren	17	1–6	Whistling Kite	2	1
Brown Honeyeater	2	1–3	Common Bronzewing	4	1–2
New Holland Honeyeater	3	1–2	Laughing Kookaburra	5	1–3
Red Wattlebird	15	1–4	Sacred Kingfisher	1	1
Striated Pardalote	12	1–2	Australian Hobby	1	1
Spotted Scrubwren	7	1–3	Brown Falcon	1	1
Weebill	3	1	White-tailed Black-Cockatoo	2	4–24
Western Gerygone	9	1–3			
Broad-tailed Thornbill	14	1–4	Red-capped Parrot	14	1–9
Yellow-rumped Thornbill	1	2	Twenty-eight Parrot	5	1–2
Grey Butcherbird	13	1–2	Regent Parrot	1	1
White-backed Magpie	10	1–4			
Black-faced Cuckooshrike	4	1–3			
Western Whistler	2	1–2			
Rufous Whistler	9	1–5			
Grey Shrike-thrush	8	1–2			
Willie Wagtail	2	1–2			
Grey Fantail	20	1–6			
Magpie-Lark	6	1–3			
Australian Raven	13	1–3			
Welcome Swallow	4	1–3			
Tree Martin	4	7–16			
Little Grassbird	1	1			
Grey-breasted White-eye	9	1–9			
Australian Pipit	1	1			

and migratory. However, although the observations were made over 33 years, most were not made in a way that would allow comparative analyses of abundance over time as has been done by Davis *et al.* (2013) or Hobbs (2022).

Although the Club's main emphasis has been on the occurrence of species, additional studies have provided information on the biology of some of the commonest birds. Keast (1975) used the Cooleenup site to make behavioural studies on how and where birds fed in the canopies of the trees and shrubs of the island. For example, he showed the Striated Pardalote feeds in the outer foliage of the tallest trees, whilst the Western Whistler and the Rufous Whistler mostly fed in the middle regions of the canopy, observing the foliage and branches and twigs above, below and on either side.

The Club's bird banding studies have provided information on the longevity of some common species on Cooleenup Island, including a Spotted Scrubwren which was recaptured after 12 years and 3 months (Table 3). Similarly, the Australian Pelican provides some information about longevity but also indicates that some banded birds travelled more than 300 km in less than a year (Table 4).

The international importance of these deltaic islands for waterbirds was recognised in 1990 when they were included in the Peel-Yalgorup Ramsar site (RIS 2006–2008). This Ramsar site supports more than 1% of the world population of 11 species of waterbird (Australasian Shoveler, Grey Teal, Musk Duck, Eurasian Coot, Banded Stilt, Red-necked Avocet, Red-capped Plover, Red-necked Stint, Sharp-tailed Sandpiper, Curlew Sandpiper and Fairy Tern) and all of these have been recorded by the Club (Table 2). This Ramsar site is also important because it is used by large numbers of migratory birds. It also has regionally and nationally significant colonies of cormorants. The Serventy 'stamp albums' record flocks of up to 300 of Little Pied, Pied, Little Black and Black Cormorants at the deltaic islands between 1968 and 1982, and the YNO diaries also record large numbers of cormorants seen in the 1990s.

Range extensions

Bird populations are not static. An example is the Australian Pelican, which is one of the most frequently recorded nesting water birds seen in the deltaic islands (Table 2). However, nesting in the Peel Inlet near Mandurah only started in 1962–63 and has continued since then (Serventy & Whittell 1976; Storr & Johnstone 1988). Another example is the Australian Wood Duck, which was first recorded at YNO in 1987, and established a breeding population (Table 2). Yellow-billed Spoonbill is yet another example; it was first recorded at YNO in 1976, and was then recorded almost every year from 1985 onwards (Table 2). Both Serventy and Whittell (1976) and Storr and Johnstone (1988) considered it to be an infrequent and very rare visitor to the south-west in the 1970s and 1980s.

Irruptions

Invasions by some species are closely related to unusual weather conditions in northern and central Australia, such as extensive flooding of the Lake Eyre basin. Some bird species undergo a boom-and-bust cycle, building up large numbers when food is abundant, and declining rapidly in drying conditions. These conditions may trigger an irruption of water birds to areas where they are uncommon. Dell (1985) recorded an irruption of White-necked Heron in the south-west of WA in 1975, and they were observed at YNO in 1975 and 1976 (Table 2). This irruption followed high rainfall in eastern and northern Australia in 1973, and in WA (apart from the south-west) in 1975.

Dell (1985) mentioned the large population increase of White-necked Heron in 1975 was mirrored by large numbers of Black-tailed Native-hen which was seen for the first time at YNO in 1975 (Table 2).

Another example of an irruption is the Australian White Ibis, first seen at Yunderup in 1975. Robinson (1961) mentioned irruptions in 1952 and 1961. In 1968, following another irruption, Bekle (1982) recorded that it became

permanently established in Wanneroo and Cockburn. Since then, it has extended its range and been recorded at YNO every year from 1985 to 2000 (Table 2).

Infrequently observed species

The long run of observations made by the Club has resulted in records of birds that are uncommon or infrequent in the different habitats on Cooleenup and other deltaic islands. These may be genuine sightings, or the birds may have been incorrectly identified.

Restless Flycatcher was recorded in 1970 (Serventy 1970) and 1988 (Table 1), although Elliott (2003) considers the 1970 record as doubtful. This is a very occasional visitor to the coastal plain (Serventy & Whittell 1976), and Storr and Johnstone (1988) considered it a casual visitor south of Loch McNess. Ford (1965) regarded it as an uncommon visitor near Perth.

Other uncommon passerines are Western Little Wattlebird, Spotted Pardalote, Black-faced Woodswallow, Varied Sittella and Australian Reed Warbler (Table 1). Both Serventy and Whittell (1976) and Storr and Johnstone (1988) consider these to be uncommon to common in the southwest of WA, however, the plant communities on the deltaic islands may not be ideal for these species.

There are some unusual sightings of non-passerines. Cape Barren Goose was recorded in 1988 and 1990 (Table 2). According to Serventy and Whittell (1976), this species is confined to the islands of the south coast east of Albany, although a bird was seen in 1942 near Busselton. If these identifications at YNO are correct, Cape Barren Goose must be regarded as a vagrant, i.e., a bird found outside its species' normal migration range or distribution area.

Amongst the ducks, Pink-eared Duck, Chestnut Teal and Hardhead have each been recorded once (Table 2). Serventy and Whittell (1976) and Storr and Johnstone (1988) consider Pink-eared Duck and Hardhead to be uncommon, whilst Chestnut Teal is rare on the Swan Coastal Plain.

There is a single record of Red-tailed Tropicbird at YNO (Table 2). This species breeds in the Abrolhos Islands (Serventy & Whittell 1976), and Storr and Johnstone (1988) consider this a rare visitor to the southwest of WA. Warham (1956) records seeing one at Busselton in 1956, and Serventy (1965) records that they were nesting near Cape Naturaliste. The southwards spread of this species may be the result of the strengthening of the warm, south-flowing Leeuwin current (Wooller *et al.* 1991).

There is one record of Glossy Ibis at nearby Coodanup. Both Serventy and Whittell (1976) and Storr and Johnstone (1988) consider it to be very infrequent to uncommon. Burbidge (1962) reports seeing one in 1962 in Peel Inlet at the Chimneys.

Australasian Bittern was observed in 1991 (Table 2). This was formerly common in the southwest of WA but is now uncommon (Storr & Johnstone 1988). Hutchison (1972) recalls seeing an Australasian Bittern perched on a *Casuarina* tree at Cooleenup Island sometime between 1940 and 1942, although Elliott (2003) considers Hutchison's observations may have been of an immature Nankeen Night Heron.

Eastern Reef Heron was seen in 1976, 1977 and 1981 (Table 2). Storr and Johnstone (1988) state this species

is scarce. Serventy and Whittell (1976) mention it had been recorded in the Peel Inlet at Yunderup.

Both Wedge-tailed Eagle and Collared Sparrowhawk occur all over WA (Serventy & Whittell 1976), but they are scarce to uncommon (Storr & Johnstone 1988).

Australian Spotted Crake was seen in 1972, 1981 and 1993 (Table 2). This is a south-west species (Serventy & Whittell 1976) which is uncommon to moderately common (Storr & Johnstone 1988). Black-tailed Native-hen is nomadic (Serventy & Whittell 1976) which may irrupt following exceptionally heavy rainfall (Dell 1985).

Painted Button-quail was recorded in 1986 (Table 2); Storr and Johnstone (1988) consider it is scarce.

The shallows of the Peel Inlet are frequented by migratory waterbirds (Table 2). Several are considered by Storr and Johnstone (1988) to be scarce or very rare visitors, these are Lesser Sand Plover, Common Redshank, Wood Sandpiper, Terek Sandpiper, Ruddy Turnstone, Long-toed Stint, Pectoral Sandpiper and Ruff. In some cases, such as Wood Sandpiper and Ruddy Turnstone, the conditions in the Peel Inlet may not be the most suitable for the species. Storr and Johnstone (1988) consider the Hooded Plover to be a scarce visitor from the interior of WA.

Gull-billed Tern were seen in 1986 and 1990 (Table 2). This species is an uncommon visitor to WA (Storr & Johnstone 1988). This is an inland tern that has only been observed in the south-west since the 1950s (Serventy & Whittell 1976).

Pacific Swift is a summer visitor to WA (Serventy & Whittell 1976; Storr & Johnstone 1988). It was recorded in 1977 (Table 2).

Brown Falcon was only recorded in 1993 (Table 2). Serventy and Whittell (1976) consider it to be one of the commonest birds of prey, while Storr and Johnstone (1988) state that it was previously very common but was now uncommon, possibly because of the widespread use of 1080 poison.

The Galah spread from further north into the Wheatbelt during the 1940s and 1950s, becoming fairly plentiful in the Perth area in the 1960s; it is a vagrant on Rottnest Island (Serventy & Whittell 1976; Storr & Johnstone 1988). Galah were recorded at YNO in 1990 and 1992 (Table 2).

It is not known which species of Corella was recorded 1975 (Table 2).

Elegant Parrot is a south-west species that occurs on cleared farmland, having recently extended its range (Serventy & Whittell 1976; Storr & Johnstone 1988). It was recorded at YNO in 1993 (Table 2).

Rock Parrot were recorded in 1973 (Table 2). This is a coastal species which Storr and Johnstone (1988) consider to be casual away from its main centres at Lancelin Island and the adjacent coast, and Rottnest Island; it was seen at Fremantle in 1950 (Reid 1951).

Changes to the Peel Inlet since 1967

The Peel Inlet has been affected by many changes since these bird records started in 1967. One of the most significant changes is the population growth in the immediate neighbourhood of the deltaic islands. Between 1976 and 2016 the population of the city of Mandurah increased from about 5000 to 83,000 and the shire of Murray from 8300 to 17,000

(Australian Bureau of Statistics 2019). The area is a major residential and recreational area for Perth with many canal developments along the Inlet, such as those immediately south of the deltaic islands (Fig. 1). Increased recreational boating, fishing and crabbing is likely to cause increased disturbance of waders feeding in the shallows (Brearley 2005).

There are additional changes to the Peel Inlet which are also likely to affect the bird population. When the Club's records started in 1967 the Inlet was frequently affected by algal blooms caused by eutrophication. These blooms resulted from phosphorus and nitrogen runoff from agriculture and horticulture in the catchments of the Murray and Serpentine Rivers (Brearley 2005). This problem was longstanding and complex with no single easy answer. An engineering solution to increase the flushing of the Inlet was proposed by the state government, and the Dawesville Channel, which connects the Inlet to the ocean, was completed in 1994. This has been effective at reducing algal blooms and increasing salinity, with the Peel Inlet becoming a more marine environment. There have been changes in benthic invertebrates, the fish populations and an increase in mosquitoes (Brearley 2005). These long-term changes are also likely to affect both the abundance and species diversity of birds in the area.

Another long-term change which may affect the bird population is the warming and drying of the climate in the south-west of WA (McFarlane *et al.* 2020). The effects are complex, with reduced rainfall, run-off and streamflow affecting the volume of fresh water reaching the Peel Inlet through the Murray and Serpentine rivers, allowing seasonal saline intrusions from the Inlet into the lower reaches of these rivers. This is likely to affect the plant communities on the islands, and the food available to land and water birds.

What started as general natural history activities of the Club has developed into a substantial record of the bird population of Cooleenup and neighbouring islands; an achievement which is a credit to all the Club members who participated.

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Obituary

Anne Mueller

29 August 1931 – 21 November 2022

Honorary Life Member, Western Australian Naturalists' Club

An Interesting Life* – Anne Mueller

(* the title of her autobiography if she'd finished it)

Anne was born in Dortmund, Germany on 29 August 1931. Her father was a housepainter and her mother an all-round hard worker. Two siblings died at a young age, so Anne grew up as an only child. Anne loved school and was a good pupil. Along with all students, she learnt English in middle school.

The war years required self-sufficiency; Anne worked in the vegetable garden, tended chickens, sewed and knitted clothing from scrap thread. Anne knitted a very nice pair of socks; but they were promptly pinched from the washing line. Toilet paper was cut-up newspaper speared onto a metal spike. To make it 'extra soft' you rubbed it, like it was washing. It was not an easy or happy childhood, but she was independent and headstrong. She enjoyed going foraging with her father, he taught her about the mushrooms; they picked acorns to roast for making coffee, and picked wild rosehips and berries. (Later she was to forage for delicious mushrooms in WA, mostly without any problems except the last trip, where she was fine as she quietly vomited all hers up in the night, whilst Otto had to be taken by ambulance to hospital, and then later her son, Robert, as they both suffered stomach problems. It led the hospital to ask if she was trying to poison her family!) Before 1945 children were evacuated to the countryside and she lived with an aunt and uncle there for 2 years and attended school there.

Anne became a very good typist and worked as a teleprinter operator. She walked everywhere (2 h return to work) to save the fare.

She met Otto at a dance and they became engaged in 1955 (Fig. 1). Anne was resourceful; she purchased some

Figure 1. Anne in Dortmund, West Germany, 1955. Photo: Otto Mueller.

copper curtain rings at the supermarket to make it look like they were married, to facilitate travel together. All their friends commented and admired how much in love they were. Otto had wanderlust and went to Australia in 1956; she joined him 18 months later. They were married in September 1957 in Whyalla, South Australia. They had a delayed honeymoon to Uluru (then known as Ayers Rock) in the days when it took four days to get there from Alice Springs, and brumbies thundered past their swags in the night (tents were the only accommodation then, and only about five tourists visited there a year!).

Anne was a cheerful, hardworking, adaptable employee and had many jobs in South Australia including dishwashing at the BHP kitchens to start with, later waitressing, typing and as a nurse's aide in a maternity ward where she didn't last long as she couldn't stand the screams and moans of childbirth.

Her parents asked her to return to Germany as Anne's mother was supposedly on her deathbed. They agreed to go back but it would take a while. In 1960 after being told by Cooks Travel they couldn't return to Germany on the $600 they had, they did their own thing. Their freight (one box) was put on a ship to Germany (via Sri Lanka, they would join the ship there). Anne and Otto flew to Calcutta and spent 6 months travelling from north to south and along the way they visited some young BHP engineers they had met in Whyalla. They lived as the locals did, very cheaply, and these were happy times for Anne, meeting new people and having new adventures. Eventually, they got to Sri Lanka, where Anne became the victim of what she was later to recount as domestic violence. They had been married just three years and had sole occupancy of a large rest house next to the beach with heavy surf. The bedroom was huge with two separate beds hung with mosquito nets. In the middle of the night, she crept to the equally large bathroom, and did not turn on the light or flush the toilet so as not to awaken Otto. Surprise! Otto saw a shadowy figure with evil intent approach Anne's bed, got his legs out quickly from under the net, and kicked with all his might. Needless to say, Anne went hysterical, and for years after, made plenty of noise when she had to get up.

From Sri Lanka, the ship brought them as far as Italy, where the passengers were discharged prematurely and given a train fare to Hamburg. After a few years in Germany, Otto was offered a job (sponsored by the German federal government) teaching the electrical trade in Nigeria. In 1965, 10 weeks before the birth of her first child, Anne boarded the ship with Otto to Africa. She had very bad renal colic but took it all in her stride (and could not let anyone know she was pregnant as that would have disqualified her from travelling).

In Aba, Nigeria, Anne had a small pineapple plantation in the backyard, made lifelong friends with locals and expats, was one of the few people to ever see ball lightning (it came into their house when only she was there), had a favourite palm wine supplier and her second child, Robert, was born in nearby Umuahia. They had a pet Putty-nosed monkey, Susie, that was very jealous of Anne; Susie didn't like anyone going near her beloved Otto!

Then came the second war that Anne was to experience, the Biafran War. One day she opened the door (with

baby on hip and toddler by hand) to find two soldiers lying on the ground aiming machine guns up at her, a very frightening experience. But it ended well, Otto arranged a meeting with the Commanding Officer to ensure their safety. His students had been sent home earlier and the soldiers took over the now empty student dormitories as barracks. The soldiers would clap their hands to gain Anne's attention and say 'Madam, would you like to see so and so?' when there were visitors. Eventually, for security reasons, it became necessary to leave Aba and head towards the nearest port city. This was Port Harcourt and the small German outpost arranged further transport.

Back in Germany, they lived in a one-bedroom flat, the same size as just their lounge room in Aba. Still, they accommodated many visitors, in-laws, Australian friends and more. After Anne's mother died, Otto was working with Siemens. Otto and Anne's English stood them in good stead, and they were offered a job in Australia after Otto had completed nine months of training with Siemens Medical. Australia was a country that both reckoned would provide a better way of life than Germany.

Perth became their final home, arriving here in May 1971. They loved the clean air, the weather, the wildlife, and the lifestyle. Anne learnt to drive in Perth and in turn inspired at least three of her friends from the Leederville Primary School tuckshop to also get their licence. She loved the independence that being able to drive gave her. They joined many demonstrations: antiwar, pro-hemp, for the forests and more. Anne spent 30 years as a Kings Park Guide, 10 years as a Royal Show volunteer and many years on the Gould League Council (where she was made an Honorary Life Member in June 2019).

Figure 2. Claudia, Otto and Anne enjoying morning tea at the Raffles, Singapore, 21 June 2014. Photo: Raffles waiter.

Anne set up a Bed and Breakfast service after her children left home. She enjoyed meeting people from all over the world. Anne and Otto continued to travel including to Lang Kawi, Singapore (Fig. 2) many times to visit a dear friend that Otto had made during his bird banding trips there, a couple of return trips to Germany and neighbouring countries of Greece, Poland, Switzerland and also Thailand to visit a student they had accommodated.

Her children also spread their wings. Claudia went to northern Queensland to study and work for five years, while Robert studied in Perth and England, and lived in Jakarta where he met his wife. Anne has two granddaughters who live in America with her son and family.

Anne adored the printed word. She loved doing crosswords and she loved reading. Her tastes ranged from non-fiction (Greek and Nordic mythology), travel accounts and autobiographies to crime fiction. She also loved jokes and kept her sense of humour to the end. She loved family, cake, ginger and dark chocolate, learning (which was the big attraction of reading), a glass of wine, going out to the theatre and dancing into the New Year.

Anne's contribution to the Western Australian Naturalists' Club

Anne and Otto had joined the Western Australian Naturalists' Club (the Club) soon after arrival in Perth and were very active in the community in many different ways. Both Anne and Otto were actively involved in the project to document the natural history of the Wongan Hills, a four-year project that commenced in 1973 and culminated in the publishing of a handbook *The Natural History of the Wongan Hills* by the Club in 1977. When Otto worked every weekend on the Club's newly built Yunderup field station, Anne

Figure 3. Fundraising for KRMB through jam sales at the local shopping centre, January 1997. The sign on the left made by Otto. Photo: Otto Mueller.

was busy sourcing and then sewing material for curtains and mattress covers for the inside. She was a master preserve maker and made thousands of jars of pickles, chutneys, jams and marmalades, the profits of which were donated (Fig. 3). "Bring and buy" stalls were initiated at the Club meetings and these were run by Anne and brought in a steady income. Some of these funds were provided to the fledgling Kwinana Rockingham and Mandurah Branch (KRMB) of the Club. It is estimated that these funds totalled at least $3,000 per year over a 10-year period. On at least one occasion Anne also facilitated a donation to KRMB from Lady McNeice, a friend and benefactor living in Singapore. The funds enabled KRMB to start work on the study and conservation of Lake Richmond and its surrounds culminating in the construction of the Anne Mueller Walk Trail around the lake. These activities resulted in Lake Richmond being added to the Register of the National Estate Database in 1992. The Anne Mueller Walk Trail was officially opened by the then Mayor of Rockingham, Cr. Laurie Smith, in 1992. The funds also contributed to the construction and operation of Naragebup, the Rockingham Regional Environmental Centre, near Lake Richmond by KRMB members. Anne's contribution to the Club was recognised by her being appointed an Honorary Life Member in 1999. She thoroughly enjoyed these activities and never lost her appreciation for the natural world. Later as Otto got into entomology, she too caught the bug. She wrote to her American friend (Claudia's godmother): 'It is exciting to see a dust speck transform under the microscope, into a wonder of nature, a perfectly formed insect, which was invisible to the naked eye'.

Anne certainly did have an interesting life and indeed a life well lived. Rest in Peace Anne, you will be missed by all whose lives you touched.

Claudia Mueller

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Western Australian Naturalists' Club

Obituary

Kevn Griffiths

18 December 1928 – 28 April 2023

Honorary Life Member, Western Australian Naturalists' Club

Early years

Kevn was born on 28 December 1928. His parents were Daisy and Alf and he had two sisters Mignon (Coral) and Bettina (Dixie). They lived in suburban Cottesloe and his secondary education was at Perth Modern School. He had his father's love of the bush and the two spent many happy holidays camping together.

Kevn's captivation with the natural world led him to become an early member of the Western Australian (WA) Naturalists' Club and the WA Gould League. The Gould League was ideal for a youngster and, as a teacher it was a perfect fit. He was a member for most of his adult life. Kevn contributed significantly to their periodical *'Nature Walkabout'* with articles and diagrams. He was a committee member for a significant period of his life along with Eric McCrum, the Serventy family, Kevin Kenneally and Dave Sieber.

It was at the Gould League School Camp at Bickley in the Darling Range, 25 km from Perth, where he met his wife to be Peggy Tuffin. They were married on 29 December 1955 and had a long and happy marriage (Figs. 1 and 2).

Kevn, the teacher

Kevn's youth took place against the background of the economic, demographic and social changes taking place in post-war WA. Initially Kevn dreamt of being a farmer, and as a young man he went off to work on a wheatbelt farm. He then returned to Perth to train as an architect. After several years, however, he decided architecture was not for him either. The prevailing shortage of teachers of the time may have influenced his decision to complete his education at the Claremont Teachers College. Within this institution Kevn joined a particularly unique cohort of friends: Eric McCrum OAM, Peter Slater, Harry Butler and Eric Lindgren - all deeply connected to the study of natural history. Kevn graduated in 1953.

Figure 1. Kevn and Peg's wedding in 1955. Photographer unknown.

Figure 2. Kevn and Peg in August 2020. Photo: Mike Griffiths.

Kevn's first teaching post was at Bullfinch in the Goldfields area of WA. The next location was on the edge of the desert at Laverton where Kevn and Peg stayed for four years. During these years, Peg gave birth to their first two children, Donna and then David. These experiences created enormous learning opportunities, not least because they were introduced to the Aboriginal cultures of the western desert people. And of an adventure of a different ilk, in a freak accident their house burned to the ground.

A significant change of scene followed at Kevn and Peg's next teaching post, Middlesex near Manjimup. Here, Michael was born. In due course the family returned to Perth and settled on a large bush block at Parkerville where Kevn taught at Mundaring and Mount Helena primary schools. The family grew to include Peter and Kayley. Kevn and his father built the family home at Parkerville over several years. The large brick house remained the family home until about 15 years ago, when Kevn and Peg decided that it was time to downsize and move to Swan View.

Another life-changing adventure for the whole family was a 6 month trip around Australia in a repurposed ambulance, modified by Kevn to accommodate the five children and a dog with added storage and sleeping arrangements for all.

In the latter years of his career, Kevn moved away from teaching at public schools to teaching problematical youth. He worked at Hillston, Stoneville (a government-run 'open' reformatory for adolescent boys on a working farm property - now closed), Koorana, in Bentley (where primary-school age children who needed assistance to develop learning and behavioural skills to return them to mainstream schooling - now closed) and Riverbank Reformatory School in Caversham (also closed).

Kevn's love and curiosity of the bush influenced the nature of his teaching. Through his entire career he invented ways to introduce the wonder of nature that surrounds us/them. One favourite story of his was when he was teaching, he established a competition to foster the interests of budding young naturalists. One young winner went on to become a very successful scientist.

Kevn was a great encourager. Even when retired, Kevn volunteered his time in many capacities. At Helena College in Glen Forrest, he conducted bushland surveys with the school children - always quietly encouraging, enthusiastic and engaged.

Peg and Kevn actively contributed to the REVISE tutoring program (Retired Educator Volunteers for Isolated Student Education) and provided much needed education support to families on station properties from the Gascoyne to the eastern Kimberley. Their students were children who were schooled at home through school-of-the-air classes when not needed for mustering or shearing duties. Kevn's curriculum regularly went beyond their textbooks to include lessons about local reptiles, frogs, birds, trees and wildflowers, and he never lost an opportunity to educate and inspire when frogs turned up after a downpour, a snake slithered past or someone brought back unusual gumnuts they'd found out in the backcountry. Kevn and Peg developed fond relationships with these Outback youngsters and their families and stayed in touch with most for many years.

Gambusia project and other wetland interests

In 1972 in pursuit of his Teachers Higher Certificate, Kevn wrote a thesis: *A study of an introduced fish, and its effect on native fish populations*. His research involved travelling widely throughout southwest WA investigating the distribution and habitats of Eastern Gambusia (*Gambusia holbrooki)*, an introduced problematic freshwater fish. These expeditions were accompanied by some of his young family, who speak fondly of the unique experience of Dad-time and aquatic splashings.

In the early 1970s little was known of this introduced species beyond the fact that it had spread to waterways across Australia and was associated with declines in inland native fish populations and other aquatic life. Kevn's study investigated its distribution and biology in the rivers and lakes of southwestern WA. He was amazed at how widespread it was, how fast it breeds and how resilient it is to poor water quality, salinity, and extreme water temperatures. As a result of his work, he became particularly concerned about its impacts on native species and was quick to highlight this and to promote knowledge of the little known native freshwater fish whenever the opportunity arose.

This Gambusia study led to Kevn becoming extremely knowledgeable about freshwater fish, freshwater crayfish and frogs (Fig. 3). He continually expanded his knowledge in different areas, and through his Gambusia studies worked with a variety of aquatic specialists and fish experts including respected naturalist Bruce Shipway (1907–1972), known for his work on freshwater fish and an interest in Gambusia.

Kevn also had other aquatic interests, including a particular passion for

Figure 3. Peg, Kevn and Twink Smurthwaite, collecting samples at a Darling Range Branch excursion. Photographer unknown.

"magic mud". Many of his former school students will remember the assorted aquariums and glass bowls containing large pieces of dry clay from ephemeral wetlands. "Just add water" he would say, "wait and watch, and you never know what will emerge". It often took many weeks to see the results from a new clod of dried clay in a tank of water, but he was always patient, checked regularly and diligently wrote notes right up until his final months. Over the years, he recorded numerous minute crustaceans and other animal and plant life after emerging from long-dormant eggs or spores. One of his greatest wishes was that more children could experience the wonders of "magic mud" and learn about this little-known but fascinating aspect of nature.

Contributions to fungal studies

Kevn was well known for writing and illustrating his book on fungi. The idea for the book was sparked when the eldest daughter Donna set out to do a school biology project on fungi, and it quickly became apparent to them both that little information on local fungi existed.

Kevn worked closely with mycologist Roger Hilton (1927–2012) from the University of Western Australia, who identified specimens as they came to hand and provided vital scientific information for the book. After eight years of hard work, *A Field Guide to the Larger Fungi of the Darling Scarp & South West of Western Australia* was self-published in 1985. The publication features Kevn's

Figure 4. Kevn's painting of *Lachrymaria asperospora* used in *A Field Guide to the Larger Fungi of the Darling Scarp & South West of Western Australia.*

water-colour paintings of 110 species of fungi (see Fig. 4) and describes them on a family basis. The book includes keys to assist with identifying the main groups of fungi, together with information about their toxicity, location and how to take useful fungi photographs. A later addition was an inserted leaflet outlining types of fungi known collectively as **skin fungi** – a poorly known 'group' of fungi and one of Kevn's later interests. The book has kept its relevance to this day and remains an important reference for the amateur and the practising mycologist (Fig. 5).

His fascination and dedication to the study of fungi continued all his life and always in collaboration with his good friend Eric McCrum. In 2001 Kevn became an inaugural member of the Fungi Study Group of the WA Naturalists' Club. In 2004, following a grant from Lotterywest, the Perth Urban Bushland Fungi (PUBF) project was launched: a collaborative project between the Urban Bushland Council and the WA Naturalists' Club in conjunction with the WA Herbarium. Among the relationships he established was with mycologist Dr Neil Bougher who remembers Kevn, "… over the years, he attended many of the fungi forays, including (up until about 2015) making the long early morning drive down from his home in the hills to join my small band of volunteers on long-term surveys at Kings Park and Bold Park. Kevn was always very patient on the forays, often waiting quietly in the background letting others have their turn first, then gleefully coming in himself to look or photograph the fungus close up."

Figure 5. Kevn with the stone-maker fungus (*Laccocephalum tumulosum*) in 2005, which he had dug up in the hills and brought to the WA Herbarium. Photo: N.L. Bougher.

Kevn frequently expressed consternation about the lack of a resident mycologist at the WA Herbarium, believing that the importance of fungi could not be overstated.

Kevn the artist and craftsman

Kevn had many passions aside from his beloved family, including art, gardening, fancy pigeons, travel, camping, keeping fit, dogs, and teaching others about the wonders of the bush. On his many bush trips he often packed an artists' easel and paintbox alongside the reference books and fungi tool kit. He loved to paint and sketch natural subjects, and he nearly became a member of the celebrated BAG (Botanical Artist Group), now synonymous with famous WA botanical illustrators. He is known for his beautiful and accurate watercolour depictions of fungi through his fungi book. More recently, he illustrated three children's books written by Betty (Elizabeth) Turton about the adventures of a spirited Border Collie dog: *Lazy Colleen* (2001), *Colleen's Horse Play* (2006), and *Colleen to the Rescue* (2017) where Colleen rescues a child lost in Dryandra woodland while looking for native animals.

Kevn's art and teaching skills took him to many places, including to the Eyre Bird Observatory, where he taught people how to draw and paint taking inspiration from nature.

Kevn was skilled with his hands and would often spend time repairing household items and tools and tinkering in his workshop. He was a keen gardener, a woodworker and a ceramicist. His sculptures depicted scenes of nature: birds and fungi and even his favourite pigeon breeds. He had an eye for accuracy, often creating figurines with scientific detail. He was known to experiment with glazes to accurately achieve the most realistic colour of his varied subjects. He possessed a remarkable studio/workshop!

Pigeons

Kevn was interested in breeding and showing fancy pigeons. He shared this love with daughter Kayley. Over many years he obtained enjoyment with experimenting in the art of breeding beautiful birds. Some of his fancy pigeons ranked highly in Australian shows and Kevn became a fancy pigeon judge at the Perth Royal Show. Even in the week before he passed, he was instructing Kayley on how to get media coverage for Australian Saddleback Pigeons in the hope of increasing appreciation of this breed.

On one occasion Kevn was transporting a cage of domestic pigeons to Queensland via another event in Alice Springs. At one picnic-area lunch stop Kevn placed the fancy pigeon cage on the ground. Spinifex Pigeons (*Geophaps plumifera*) came to the cage to take the cage's seed, providing a close-up of the wild birds.

Darling Range Branch

Determined to maintain the pursuit of investigating nature, Kevn and Peg, along with long-term friends Eric and Margaret McCrum, decided that driving a total of nine children down to Nedlands from Parkerville on a monthly basis was not much fun. This was the trigger to set up a 'Hills' branch of the Naturalists' Club. The first Darling Range Banch (DRB) meeting was held at the rustic Mundaring Weir Hall in 1974 with

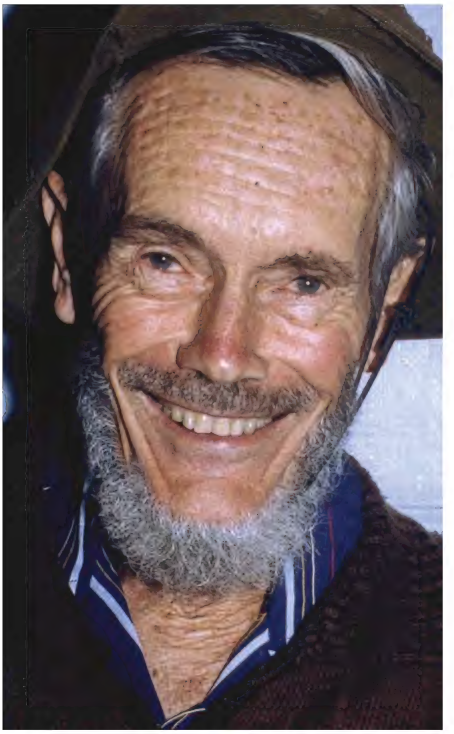

Figure 6. Kevn, a true gentleman. Photographer unknown.

about 20 people attending, including children and pigeons nesting in the ceiling! DRB held their first Wildlife Show at Mundaring Showgrounds later that year, complete with a range of live birds and animals, including a 'Thylacine' (aka the Griffiths' family dog painted with blue stripes)! It was an extremely popular event and saw more members join the DRB. By 1976, the DRB had 24 adult and 10 junior members. Another successful Wildlife Show was staged in 1983. The Branch is still going strong today. And for almost its 50 year duration Kevn has held a position on its committee.

In 1994, Kevn became an honorary life member of the Western Australian Naturalists' Club. This was awarded in recognition of his enduring commitment and involvement in the pursuit of natural history and through his role in establishing and upholding the DRB.

Kevn's legacy

Kevn was widely known as a loving, kind, loyal, compassionate and generous man with a lively sense of humour (Fig. 6). An optimist by nature, he always saw the good side of people. His legacy will continue through his children and the people whose lives he touched. He truly embodied the qualities of a gentleman and a nature enthusiast, leaving behind a positive impact on the world. The final word will go to his wife Peg. "To me he was a loving husband and father, and a true gentleman to all". Vale Kevn Griffiths.

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From Field and Study

First record of the Chequered Copper butterfly *Lucia limbaria* (Swainson, 1833) (Lepidoptera: Lycaenidae) from Western Australia

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An isolated population of the monotypic lycaenid butterfly, the Chequered Copper *(Lucia limbaria),* is recorded and photographed in Western Australia for the first time from a remote site near Balladonia. The population is approximately 1700 km from its closest conspecific near Adelaide, South Australia. We discuss the possible origins and status of this isolated population based on our observations of this new butterfly for Western Australia.

The Chequered Copper butterfly (*Lucia limbaria*), also known as the Small Copper or Grassland Copper, is a small Lycaenid butterfly species endemic to Australia. The species typically has a patchy distribution in open and semi-arid grassland areas in mainland eastern Australia extending as far west as Brinkworth north of Adelaide in South Australia (Grund 1996; Braby 2016). Additionally, one unverified record exists from Lord Howe Island (Smithers 1971). On 20 April 2023, during a routine flora survey at a remote Balladonia location, two small butterflies were observed on an isolated track traversing a chenopod shrubland. The butterflies were flushed from the track when SMH approached them to photograph; however, they quickly settled a short distance away allowing for closer examination and close-up photography (Fig. 1). An initial identification of *L. limbaria* by SMH was confirmed by Michael Braby (Butterflies Australia) from photographs of the butterflies and he noted that they were not previously known from Western Australia. Here we report the first occurrence of *L. limbaria* in the state of Western Australia as well as the first occurrence of the species in the western half of the continent (Fig. 2). We discuss the possible origins and status of this new butterfly for Western Australia.

Habitat in the vicinity of Balladonia where *L. limbaria* were found is described as a chenopod shrubland dominated by *Atriplex* spp., (saltbush) and *Maireana* spp., (bluebush) with

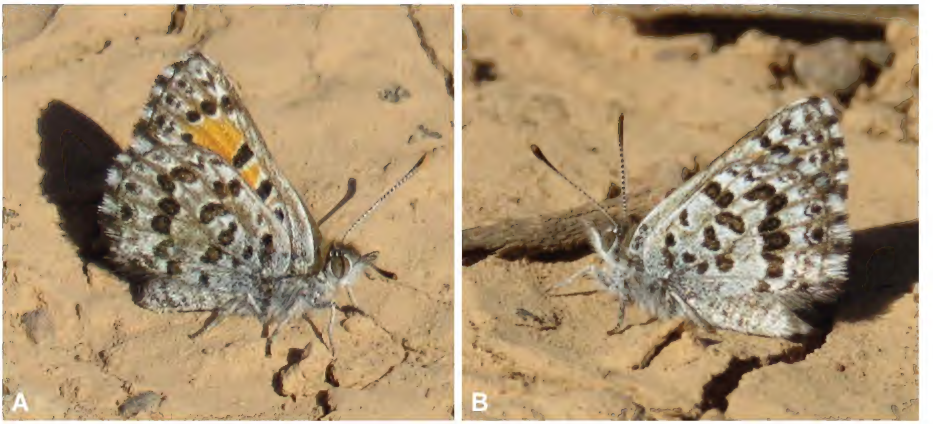

Figure 1. (A) Female Chequered Copper (*Lucia limbaria*) photographed in Balladonia, WA. Note the rusty coloured patch clearly visible on the underside of the forewing. (B) Male. Note that the patch is not visible due to overlapping hindwing. Photos: S. Henkanaththegedara.

scattered trees such as *Eucalyptus* spp. and *Acacia* spp. (Fig. 3A). At the observation site, the ground was patchily covered with *Oxalis perennans* (Oxalidaceae) (Fig. 3B), a known larval food plant of *L. limbaria*. Also present were flowering *Brachyscome ciliaris* (Asteraceae), a major nectar source for adult butterflies (Braby 2016) (Fig. 3C). An inspection of similar habitats dominated by chenopod shrublands at 55 locations in the western Nullarbor region between Balladonia and Cocklebiddy, recorded *O. perennans* from only four locations close to Balladonia and failed to locate additional populations of *L. limbaria*.

The two adult butterflies were active around 9:30 am on a sunny and breezy morning. Both individuals appeared to be freshly emerged as can be seen in Figure 1 and when disturbed they "fluttered" only a short distance before landing. Only the undersides of the butterflies were visible due to their posture. Underside markings consisted of a series of dark brown spots fringed with white on a light brownish-grey background and the outer margins of both wings were chequered with a brown and white fringe. The female (Fig. 1A) can be distinguished from the male by darker markings on the undersides of the wings and body as well as the larger abdomen. Both sexes have a rusty orange (copper) coloured patch on the underside of the forewings; however, the patch is only visible in the photo of the female (Fig. 1A) since the male patch is obscured by the hindwing (Fig. 1B). *Lucia limbaria* measure about 25 mm across the open wings (Braby 2016).

The average annual rainfall in Balladonia is 310.7 mm with an average monthly rainfall of 34.2 mm in March and 20.6 mm in April (average for 1991–2020 period; BOM 2023) (Fig. 4). Weather patterns in the Balladonia area leading up to the new discovery were reported as a total rainfall of 19.8 mm and 22.8 mm in March and

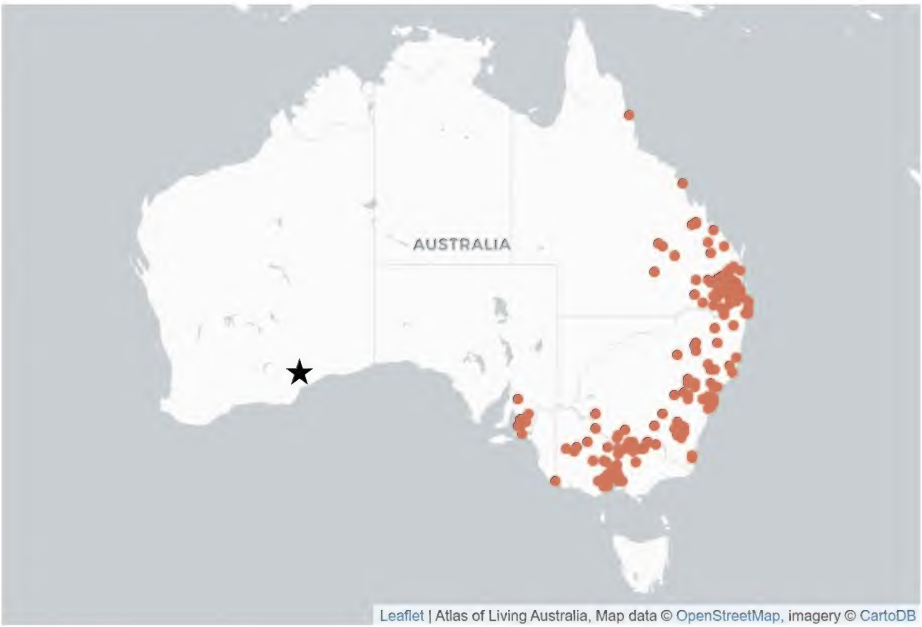

Figure 2. Current distribution of the Chequered Copper (*Lucia limbaria*) in Australia is indicated by red dots. Approximate location of the Balladonia observation is marked with a black star. The base map was adapted from the Atlas of Living Australia (ALA 2023).

April of 2023, respectively (BOM 2023). The average monthly temperatures in March and April were 29.4°C and 23.4°C, respectively (BOM 2023).

The discovery of this isolated *L. limbaria* population at the western end of the Nullarbor Plain, some 1700 km from the closest breeding population near Adelaide, raises several questions about its origin and status. It seems unlikely that the butterflies arrived recently from the east across the Nullarbor since the 1700 km gap of inhospitable environment for a small butterfly with specific ecological requirements would be a formidable obstacle. If they did not arrive recently then why have they not been found before now? This may be due to the remoteness of vast areas of Western Australia and a low density of field entomologists compared with the eastern states. Furthermore, *L. limbaria* can be easily overlooked since it is a small butterfly with a cryptic colour pattern, and generally flies very low to the ground. Also, several studies report that the species is unpredictably encountered in suitable habitat (Douglas & Braby 1992; Braby & Edwards 2006) potentially making it difficult to find in any given location.

The records of known *L. limbaria* populations shown in Figure 2 highlight their anthropocentric distribution around the major east coast cities of Brisbane, Sydney, Canberra, Melbourne and Adelaide as well as other regional centres. This pattern supports our claim that the

Figure 3. (A) The chenopod dominated landscape at the location where Chequered Copper butterflies (*Lucia limbaria*) were observed. (B) A potential larval food plant, *Oxalis perennans* (Oxalidaceae) and (C) an adult butterfly nectar source, *Brachyscome ciliaris* (Asteraceae) observed at the site. Photos: S. Henkanaththegedara.

paucity of collecting effort and the cryptic nature of *L. limbaria* rather than absence of the species is why they have not been found in Western Australia before now. It seems likely that the range of *L. limbaria* in Western Australia will be more extensive, but perhaps difficult to confirm.

The observation of *L. limbaria* in close proximity to its *Oxalis perennans* hostplant in a low relief landscape with short vegetation cover (Fig. 3A) is consistent with the habitat at many *L. limbaria* sites in the eastern states (Braby 2016; RE, *pers. obs.*). Adult butterfly appearances, especially small lycaenids in Western Australia, are often tied to plant phenology (RE & AAEW, *pers. obs.*). This may include host plant leafing out or flowering

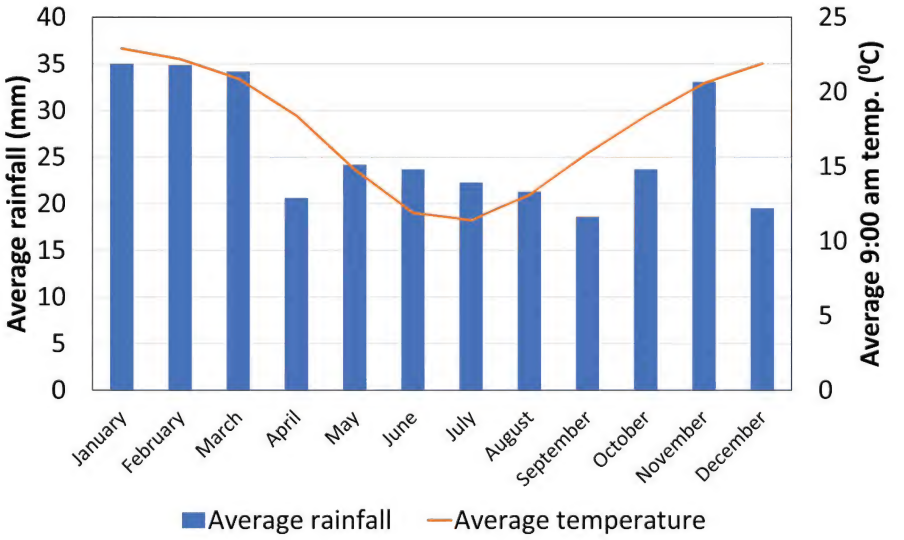

Figure 4. Average monthly rainfall and 9:00 am temperature for Balladonia area for 1991–2020 (BOM 2023).

as well as the flowering phenology of nectar plants such as *Brachyscome ciliaris* which was flowering at the Balladonia site. Braby (2016) also reported that the adults obtain nectar from the flowers of low-growing *Helipterum* and *Helichrysum* daisies (Asteraceae), and their host plant, *Oxalis* spp., which was also flowering at the Balladonia site (Fig. 3B).

Larvae of *Lucia limbaria* have a mutualistic association with ground-dwelling *Iridomyrmex* ants (Eastwood & Fraser 1999; Braby & Edwards 2006), but it is unknown if ant nest events such as alate development, nuptial flights or foraging patterns are relevant to their butterfly symbionts. Butterfly larvae feed openly on the food-plant foliage during the day (Braby 2000) but when not feeding may reside inside the ant nest where they also pupate (Quick 1972). Males establish territories at breeding sites where their larval food-plants and attendant ants are present (Braby 2000, 2016).

The Atlas of Living Australia (ALA 2023) data shows that most of the observations and collections in eastern Australia have been made between October and April, with fewer observations in winter. Weather pattern events recorded prior to the discovery of freshly emerged *L. limbaria* adults at Balladonia suggest they emerge in autumn after the end of the summer rains but when temperatures are still warm (>23°C). The timing of these conditions is consistent with autumn flight times on the east coast where the species is bivoltine (Braby 2000). Therefore, it is possible that there will be a spring flight of *L. limbaria* at Balladonia in late September–October when temperatures and rainfall patterns are similar to the autumn conditions.

This record of *L. limbaria* in the remote western Nullarbor region of Western Australia more than 1700 km west of the nearest known population in South Australia is remarkable but not unique. Another closely related lycaenid butterfly, the Bronze Ant-Blue (*Acrodipsas brisbanensis*), with a similar distribution to *L. limbaria* on the east coast, has been found at Yanchep north of Perth, and there are no known intermediate populations of this species (Williams *et al.* 1992). Even more remarkable is that the population in Yanchep shares a genetically identical haplotype (582 bp mitochondrial Cytochrome Oxidase subunit 1 gene) with another population at Pine Mountain, Victoria, some 3000 km distant (Eastwood & Hughes 2003).

This new record of an "eastern butterfly" species in "the west", a long way out of its range, raises questions about our understanding of the true diversity of butterflies in remote parts of Australia. Citizen science projects such as Butterflies Australia (https://butterflies.org.au/) may play an important role in documenting the diversity of lepidopterans in an isolated continent full of poorly explored remote areas.

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From Field and Study

Fasciation affecting floral development in the cow-kicks triggerplant (*Stylidium schoenoides*)

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We report here a case of fasciation in the cow-kicks triggerplant (*Stylidium schoenoides*), a member of the plant family Stylidiaceae. In triggerplants, pollination is achieved through the deployment of a sensitive 'trigger', that comprises the male and female reproductive organs fused at the apex to form a floral column. The trigger snaps forward in response to touch, harmlessly covering the visiting insect with pollen. After triggering, the column resets to its original position. For seven years, one of us (JS) has been observing and photographing a population of fasciated cow-kicks growing in a patch of coastal heath in the Gracetown area of south-west Western Australia. The fasciation results in increased petal number and malformation and splitting of the floral column or trigger. We are not aware of any other reports of fasciation in triggerplants.

Fasciation is typically a mutation or deformity that occurs in the meristem where cells begin to form. These cells divide and then specialise, becoming the cells that make up the leaves, stems and flowers. Fasciation can also be caused by random genetic mutation, bacterial or viral infections. Some species of plants have a genetic predisposition toward fasciation and can show the symptoms relatively frequently, but for most plants its appearance is a rare or one-off event. It often leads to multiple extra flowers produced on the affected stems, typically with many secondary blooms surrounding the normal, expected one. The flowers themselves may appear flattened or elongated, crushed together or otherwise misshapen.

The fasciated cow-kicks grow in a 6 m^2 area of low coastal heath occurring on grey-brown sand with a bleached surface derived from granite gneiss near the west coast of the Leeuwin-Naturaliste Ridge. Dominant or characteristic shrub species include *Calothamnus sanguineus, Darwinia citriodora, Hakea prostrata, H. trifurcata, Jacksonia horrida, Kunzea ciliata, Pimelea ferruginea, P. rosea, Spyridium globulosum, Verticordia plumosa* var. *plumosa* and *Xanthorrhoea brunonis*. Common herbs include the grasses and sedges *Asteridea pulverulent*a, *Rytidosperma setaceum, Austrostipa compressa, Brachyscome iberidifolia, Lepidosperma squamatum, Platysace*

haplosciadia, *Trichocline spathulata* and *Velleia trinervis* (Shire of Augusta Margaret River 2020) (Fig.1).

Stylidium schoenoides is a perennial herb, endemic to the south-west corner of Western Australia, extending north to Mt. Lesueur and south to Albany and Hopetoun. It grows to a height of 0.5 m. The leaves are basally tufted; 14–35 cm by 1–1.8 mm and hairless, with membranous scale leaves present at the base of mature leaves. The flower stalk has glandular hairs and long soft weak hairs. The flowers have four corolla (petal) lobes in two unequal pairs, more-or-less rounded, paired vertically, the upright pair curved, the extended pair occasionally united

Figure 1. Study area showing fasciated cow-kicks (*Stylidium schoenoides*) habitat in coastal heath at Gracetown. Photo: John Szymanski.

Figure 2. Typical cow-kicks triggerplant (*Stylidium schoenoides*), showing the four petals, four throat appendages and the floral column (trigger) bent downwards below the petals, in the set position. Photo: John Szymanski.

to the middle, with four unequal appendages spreading downwards into the throat. The labellum (a modified minute fifth petal) is recurved, ovate, with two appendages that the recurved trigger, while poised, sits against. The white-cream flowers are the largest in the genus and flowering occurs from August to November (Fig. 2).

From the throat of a *Stylidium* flower arises a slender floral column formed by the fusion of the filaments (or stalks which usually support the anthers) and the style (which usually supports the stigma) forming the trigger. The unique feature of triggerplants is their sensitive column or 'trigger' activated by visiting insects. The trigger remains reflexed in the 'cocked' position until an insect probes the flower. It then springs upwards and deposits pollen on the head or back of the insect which then transfers the pollen to another flower. The trigger, over time, will then reset. In normal triggerplant flowers, the two, two-celled anthers, mature before the stigma, opening by longitudinal slits and are located at the apex of the floral column. As the flowers age, the anthers shrivel, and the usually hairy and cushion-shaped stigma pushes up between them.

In fasciated flowers of *Stylidium schoenoides*, it is the petals and the floral column (or trigger) that exhibit change. Plants may produce flowers with 6–10 petals, with the floral column (trigger) becoming turgid and erect, and the filaments supporting the anthers and style appearing to separate. This results in a lack of mobility of the floral column (Figs. 3 and 4). Further

Figure 3. Fasciated cow-kicks flower showing the development of multiple petals and the turgid and erect floral column with the hairy cushion-shaped stigma exposed. Photo: John Szymanski.

Figure 4. Fasciated flower with ten petals, showing the turgid and erect floral column separating into the anther and style filaments. Photo: John Szymanski.

observations are needed to evaluate the effect of fasciation on seed set.

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